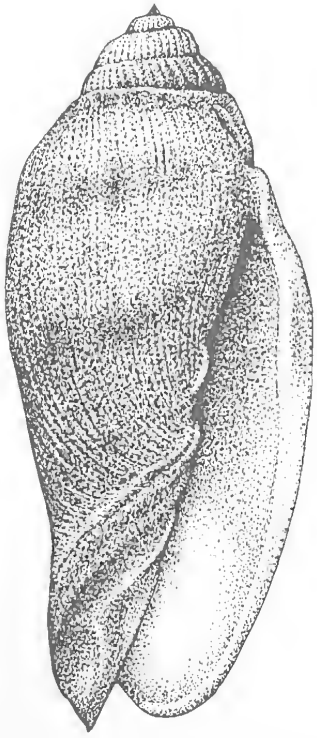
ISSN 0312 3162

Records of the Western Australian Museum



Volume 22 Part 1 2003

Records
of the
Western Australian Museum

The *Records of the Western Australian Museum* publishes the results of research into all branches of natural sciences, and social and cultural history, primarily based on the collections of the Western Australian Museum and on research carried out by its staff members.

Collections and research at the Western Australian Museum are centred on Earth and Planetary Sciences, Zoology, Anthropology, Archaeology and History. In particular the following areas are covered: systematics, ecology, biogeography and evolution of living and fossil organisms; mineralogy; meteoritics; anthropology and archaeology; history; maritime history and maritime archaeology; and conservation.

Western Australian Museum
Francis Street, Perth, Western Australia 6000
Tel. (08) 9427 7000
Fax. (08) 9427 2882
E-mail ann.ousey@museum.wa.gov.au

Minister for Culture and the Arts	The Hon. Sheila McHale MLA
Chair of Trustees	Dr Ken Michael AM BE (Hons), DIC, PhD, FTS, Hon FIE Aust, FCIT, FAIM
Executive Director	Dr Gary J. Morgan B.Sc. (Hons), Ph.D.
Editor	Dr Fred E. Wells B.Sc., M.Sc., Ph.D.

The *Records of the Western Australian Museum* is published approximately three times per year. A series of *Supplements* is also produced. The *Records* are available for sale and exchange, the current price being $11 plus postage per part. Each volume comprises four parts. Subscriptions can be taken out for whole volumes at a rate of $33 plus postage. Supplements can be purchased from the W.A. Museum Bookshop. Prices on request. Prices include GST.

Printed and published by the Western Australian Museum
© Western Australian Museum, December 2003
ISSN 0312 3162

Cover: *Volutoconus hargreavesi calcarelliformis* (Wells and Morrison, 2003), a new subspecies of volute from the deep waters off northwestern Australia

Illustration by Jill Ruse.

Records of the Western Australian Museum **22**: 1–7 (2003).

The 3-dimensional anatomy of the North-Western Marsupial Mole (*Notoryctes caurinus* Thomas 1920) using computed tomography, X-ray and magnetic resonance imaging

Natalie Warburton[1], Christopher Wood[2], Christopher Lloyd[2], Swithin Song[2] and Philip Withers[1]

[1] Department of Zoology, University of Western Australia
Crawley, Western Australia, 6009. E-mail: nwarbo@cyllene.uwa.edu.au

[2] Department of Radiology, Royal Perth Hospital
Wellington Street, Perth, Western Australia, 6000

Abstract – The 3-D skeletal images obtained from reconstruction of CT scans and X-rays, and soft-tissue images produced by MRI, provide invaluable information of the internal and gross anatomy of the north-western marsupial mole (*Notoryctes caurinus*).

The conical skull, which is quite thin-walled dorsally and anteriorly but strong in the basicranial region, has little evidence of the orbit or zygomatic arch, and the smoothly-curved posterior region has no sagittal or occipital crests. The vertebral column is remarkably strengthened, and in lateral view has an unusual flat-shape. The cervical vertebrae appear to be greatly compressed; 4 or 5 are completely fused (which is unique among marsupials). The thoracic vertebrae are fairly robust with large neural spines. The lumbar vertebrae are distinct, becoming large posteriorly towards the pelvis. The sacral vertebrae are greatly expanded in size and are fused with the pelvis. Particularly in the middle of the tail, the caudal vertebrae are greatly developed, with large transverse processes and chevron bones. The pectoral girdle is very anterior, with the shoulder articulation level with the anterior cervical vertebrae just behind the skull, and low on the side of the body. The humerus is robust, and the radius and ulna are very short. The bones of the pelvis are highly derived, and fused to sacral vertebrae. The epipubic bones are small and not ossified. An ossified patella is present and it has an unusual large triangular keel.

The most apparent soft-tissue structure by MRI is a large amount of subcutaneous fat, particularly around the ventral surface of the pelvis but also dorsal to the pelvis and anteriorly around the shoulders. The major muscle groups are visible, but distinction between individual muscles is not possible except for the very large muscles of the thigh, upper arm and base of the tail. The muscles of the tail are strongly developed, more so ventrally than dorsally.

INTRODUCTION

Computed tomography (CT scan) and magnetic resonance imaging (MRI) are used extensively in medical diagnostics and research and the techniques have also been incorporated into the veterinary discipline in clinical situations. However, the zoological use of such technology in more basic anatomical research has been rather limited. The few anatomical investigations incorporating CT and MRI technology include descriptions of the internal anatomy of the feline abdomen (Samii *et al.* 1999), and the brain and coelomic cavity of the domestic pigeon (Romagnano *et al.* 1996). The techniques have also been used in paleaontological studies, for example the measurements of brain size in *Allosaurus* (Rogers 1999). This research uses CT scan and MRI techniques to investigate the anatomy of the marsupial mole.

The anatomy of the North-western marsupial mole, *Notoryctes caurinus* (Marsupialia: Notoryctidae), has not been studied in any detail since its original description by Thomas (1920). In fact the only published research for this remarkable fossorial marsupial since then is the physiological study of Withers *et al.* (2000) and a natural history account by Thompson *et al.* (2000–2001). Very few preserved specimens of *N. caurinus* are available, so it is important to glean as much anatomical information as non-destructively as possible from the few specimens that are available. The purpose of this paper is to provide an account of the usefulness of CT scan, X-ray, and MRI to describe *N. caurinus*, a small (mass ~ 30 – 35 g) and highly specialized marsupial.

METHODS

The primary specimen of *N. caurinus* which we examined was from the Western Australian Museum (specimen number M 44175). Capture locality was Cotton Creek (Newman-Canning Stock Route road; 4/3/1999; 22°59' 122°23'). The specimen was formalin fixed and preserved in 70% ethanol. The specimen was male, with a total body length of 10.5 cm and mass of approximately 35 g.

CT and MRI scans were performed at Royal Perth Hospital, Perth, Western Australia. The CT scans were made with on a GE Cti scanner (General Electric Medical Systems, Milwaukee, USA) using a helical technique with a slice collimation of 1 mm, and a pitch of 1:1. Images were reconstructed at an interval of 0.3 mm using soft tissue and bone algorithms. 3-D volume rendered images were also obtained using the AW 3.0 workstation.

MRI scans were performed using a Marconi 1.0T MR scanner (Marconi Medical Systems, Highland Heights, Ohio, USA) using a 3-D RF FAST sequence with 1.4 mm slices, flip angle of 35 degrees, TR of 24 ms, TE of 6 ms, field of view of 12 cm, 192x256 matrix, one signal average. Images were acquired in the coronal, transverse and sagittal planes. The specimen was placed in a dedicated (human) knee coil.

X-rays were taken by Dr Ken Aplin of the Western Australian Museum, using standard x-ray film and processing techniques. The fine details of the images were verified by dissection.

RESULTS AND DISCUSSION

Computed tomography was most useful for examining hard, bony structures of the body (Figure 1). Such 3-D images of the skeleton of *N. caurinus* are useful because no fully-articulated specimen of this species is locally available, and because the functional form of its skeleton cannot necessarily be inferred from simple reconstruction of disarticulated bones because of its unique fossorial lifestyle among marsupials. Thus, 3-D computer reconstructions of CT scans provide invaluable information concerning the normal *in situ* skeletal arrangement. X-rays were necessary to provide fine detail of skeletal structures. MRI was useful in viewing the internal arrangement of soft tissue structures.

3-D Skeletal Reconstruction

The axial skeleton, comprising the skull, vertebral column, sternum and ribs, and tail of the north-western marsupial mole is highly adapted for its fossorial lifestyle (Figure 1). From the lateral view of the skeletal image, the skull is conical in shape (Figure 1C). The skull of *N. caurinus* appears to be quite thin-walled dorsally and anteriorly, but strong in the basicranial region. Teeth are not apparent on the CT scans because they are too small to be resolved by a scan of 1.0 mm slice size. The skull, including the major contours and teeth, is finely imaged by X-ray (Figure 2). The rostrum curves ventrally slightly, anterior to the molar teeth. There is little evidence of the orbit or zygomatic arch. The posterior region of the skull is smoothly curved with no sagittal or occipital crests.

The vertebral column is remarkably strengthened, and in lateral view has an unusually flat shape (Figure 1C). Overall, the form of the vertebral column appears highly specialised for burrowing. While CT resolution is not quite adequate for the fine detail of vertebrae, it is apparent that they are very robust. The cervical vertebrae are obscured by the pectoral girdle, but appear to be greatly compressed and follow a deeply concave path to the base of the skull. This unusual form of the cervical vertebrae is best seen from the lateral view of the skeletal images (Figures 1C, 2B). Fusion of the cervical vertebrae is extremely unusual for mammals, and is unique among marsupials for the marsupial mole. The thoracic vertebrae are not seen as separate entities in the 3-D skeletal images. The shape of the vertebral column in the thoracic region follows a sharp incline behind the pectoral girdle and then flattens out considerably. The vertebral column of more generalised quadrupeds follows a wider curve than that apparent for *N. caurinus* (Slijper 1946).

The lumbar region is best seen from dorsal view (Figures 1A, 2A). The lumbar vertebrae are distinct, becoming large posteriorly towards the pelvis. Their transverse processes can just be discerned on CT images. Like the posterior thoracic vertebrae, the lumbar vertebral region is very flat in shape. The sacral vertebrae are greatly expanded in size and are fused with the pelvis. The wide metapophyses are broadened to form a shield-shaped arrangement when viewed from the dorsal aspect (Stirling, 1891; Chapman, 1919).

An unusual feature of the vertebral column from the dorsal view is the arrangement of vertebrae in the tail (Figure 1). Particularly in the middle region of the tail, these caudal vertebrae are greatly developed; large transverse processes and chevron bones (apparently fused to the vertebral bodies) are evident on the CT scans. From the lateral aspect, the caudal vertebrae are almost as large as the thoracic and lumbar vertebrae, which is most unusual. Generally, caudal vertebrae of mammals are smaller and simpler in form than the thoracic or lumbar vertebrae. The large size of the marsupial mole's caudal vertebrae, the development of transverse processes for muscle attachment, and the large size of the chevron bones, suggest that the tail is highly mobile, muscular and probably involved in burrowing locomotion (see Withers *et al.*, 2000).

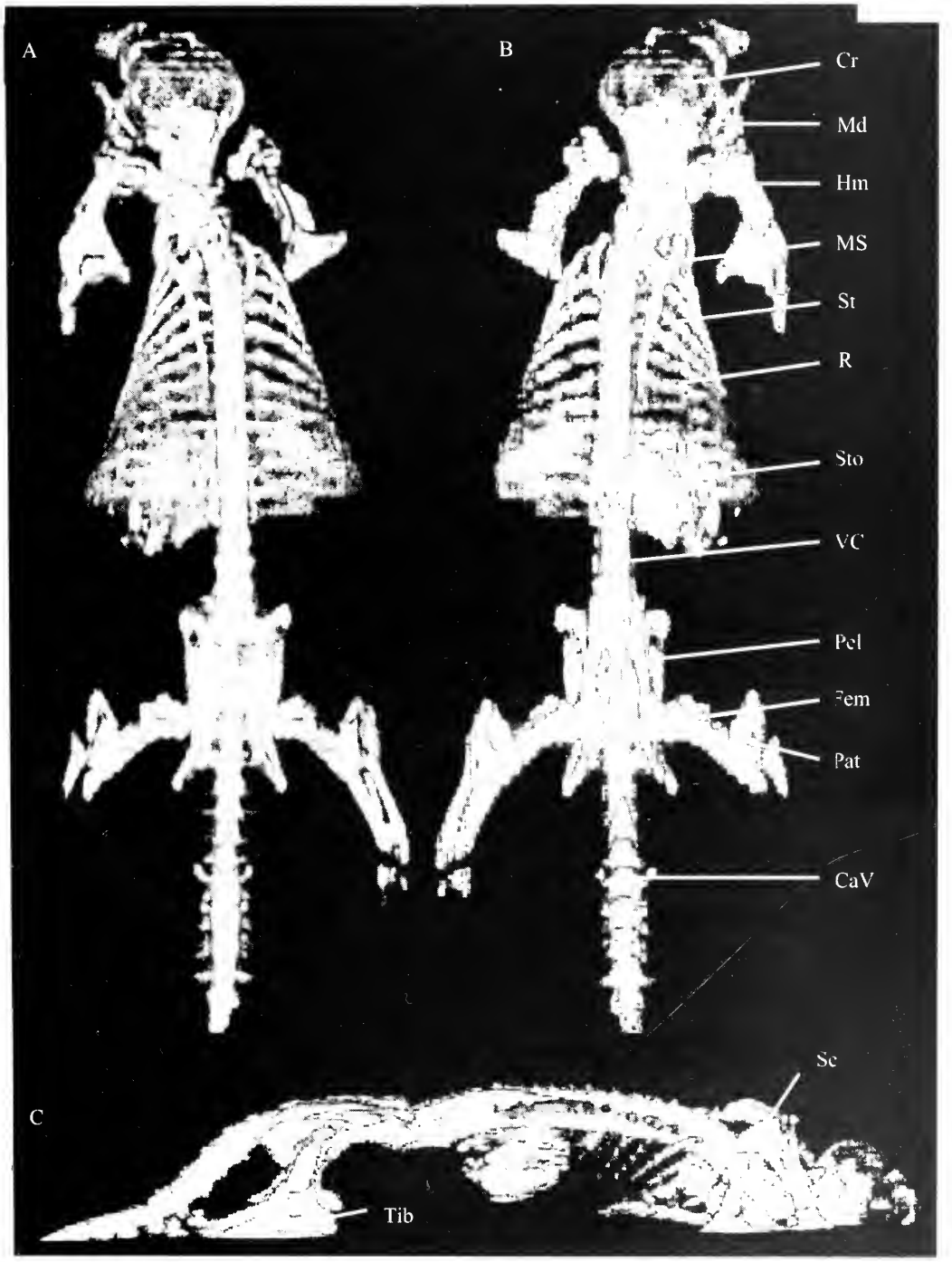


Figure 1 Computed tomography images of the three-dimensional anatomy of the North-Western Marsupial Mole, *Notoryctes caurinus*; **a** dorsal, **b** ventral, and **c** lateral views. Caudal vertebrae (CaV), cranium (Cr), femur (Fem), humerus (Hm), mandible (Ma), manubrium sterni (MS), patella (Pat), pelvis (Pel), ribs (r), scapula (Sc), sternum (St), stomach (St), tibia (Tib), vertebral column (VC).

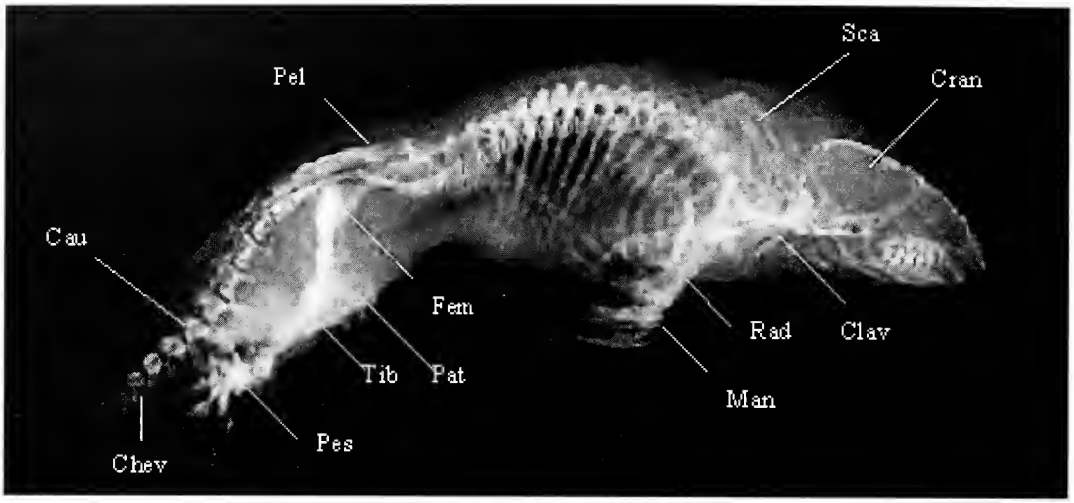


Figure 2 X-ray of the North-Western Marsupial Mole, *Notoryctes caurinus* (WAM M41482); lateral view. Actual body length (snout-tail) = 102 mm. Legend: caudal vertebrae (Cau), chevron bones (Chev), clavicle (Clav), cranium (Cran), femur (Fem), manus (Man), patella (Pat), pelvis (Pel), pes (Pes), radius (Rad), scapula (Sca), tibia (Tib).

The ribs and sternum can be clearly seen in the CT skeletal images. The rib cage is in the form of a wide cone, being very narrow anteriorly and expanding quite widely posteriorly (Figure 1A, B). The ribs appear to become less dense posteriorly. The costal cartilages, which join the ribs to the sternum, cannot be seen. The anterior part of the sternum is characterised by two large lateral processes of the manubrium.

The appendicular skeleton includes the pectoral and pelvic limbs and their girdles. The highly modified morphology of these skeletal components in the marsupial mole can be seen in the 3-D skeletal reconstruction (Figure 1). Most noticeably, the pectoral girdle is quite anteriorly placed. The position of the shoulder articulation, of the glenoid region of the scapula and the humerus, appears level with the anterior cervical vertebrae, just behind the skull, rather than the more common position of level with the anterior thoracic vertebrae (Hildebrand, 1988). In the lateral view, it is apparent that the shoulder articulation is placed quite low on the side of the body. This antero-ventral position of the pectoral girdle is characteristic of the position for other small fossorial mammals (Gambaryan and Keilan-Jaworowska, 1997).

The individual components of the pectoral girdle can be seen with reasonable clarity (Figure 1). It is apparent that the scapula is substantially modified, being narrow for the most part and fanning out posteriorly. The orientation of the scapula is also modified from the usual dorsal arrangement of the scapula in mammals (Hildebrand, 1988), occupying a more laterally-facing position (Figure 1C). The robust humerus can be seen most clearly in the dorsal views of the skeletal image; however this may include parts of the ulna included with the distal end of the humerus. Unfortunately the antebrachium (lower arm) and the manus were not represented in the skeletal images. This is quite unexpected as the bones of this region are relatively more robust than, for instance, the ribs, which were seen clearly in the skeletal reconstruction images.

The pelvic girdle is perhaps the most clear component of the skeleton. The bones of the pelvis are obviously highly derived and are fused to a number of the sacral vertebrae. The typically (for mammals) elongate innominate bones are broad and fused with expanded elements of the sacral vertebrae (Hildebrand, 1988). The fusion between the pelvis and the sacral vertebrae of marsupial moles is more extreme than in other placental burrowers, such as armadillos and pocket gophers (Chapman, 1919). It is evident that the pubic symphysis is either unfused or formed by very thin bone. The epipubic bones of marsupial moles are vestigial and are not seen in the CT scan images.

The hind limbs of *N. caurinus* extend almost laterally from the body, rather than ventrally, and the tibiae lie flat against the ground. Mammals generally have a parasaggital arrangement of the limbs under the body (Hildebrand, 1988); the abducted posture of the hindlimbs in marsupial moles is reminiscent of a more reptilian stance. The long bones of the limb are relatively robust, but no fusion between the elements has taken place. An unusual feature is the large triangular keel of the

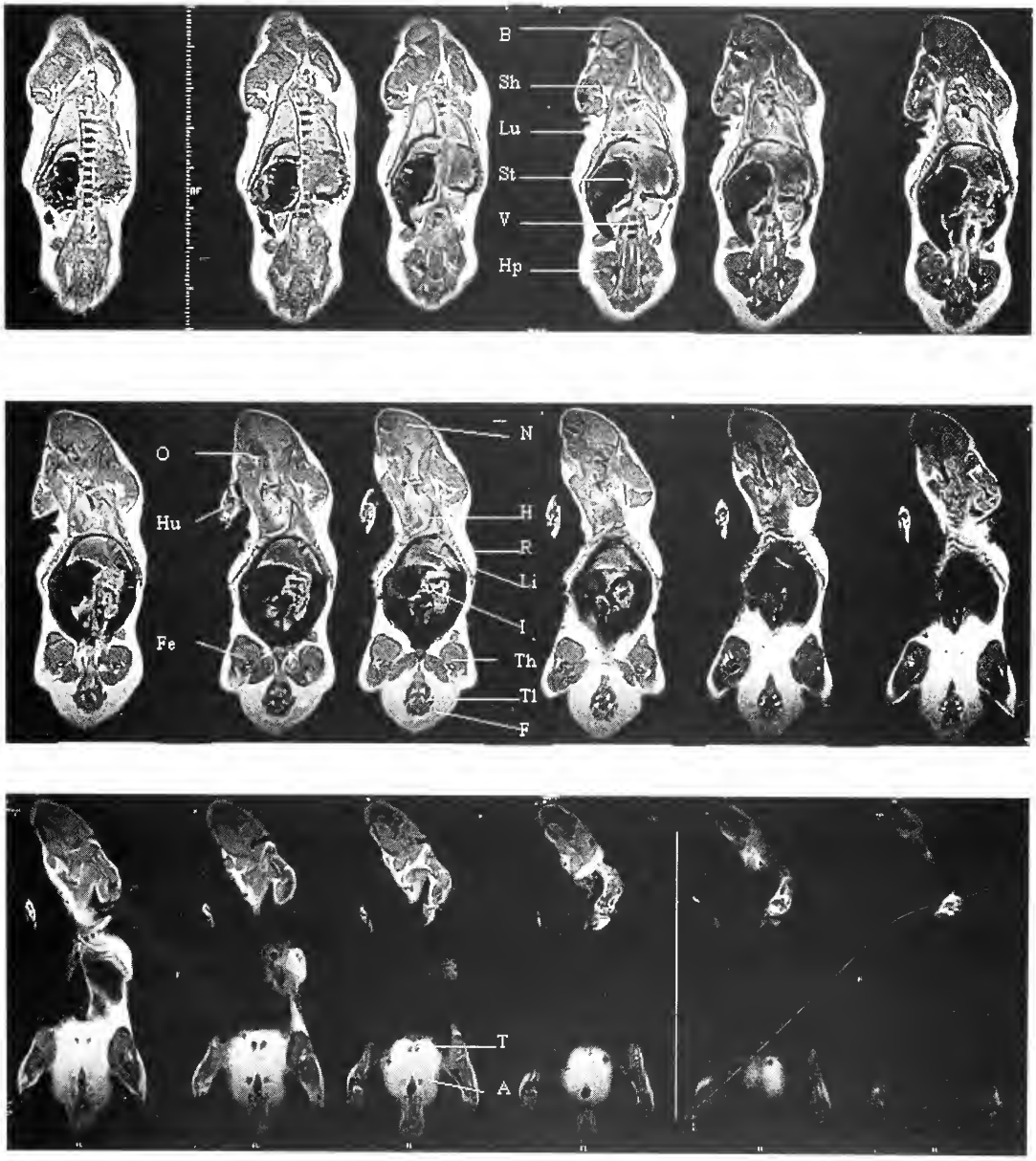


Figure 3 Magnetic resonance image of the three-dimensional anatomy of the North-Western Marsupial Mole, *Notoryctes caurinus*, sections through coronal view, dorsal to ventral. Organs visible: anal gland (A), brain (B), fat (F), femur (Fe) heart (H), hip musculature (Hp), humerus (Hu), intestine (I) liver (Li), lungs (Lu), nose shield (N), oral cavity (O), rib cage (R), shoulder musculature (Sh), stomach (St), tail musculature (Ta), testes (T), thigh musculature (Th), and vertebral column (V).

patella at the knee joint of the hind limbs (Figure 1C). Few other marsupials (only bandicoots) have an ossified patella, and none have one resembling the relatively large, irregular patella of *Notoryctes*. The tibia and fibula are pictured for the right leg only, but are clearly quite robust for an mammal of this size. Unfortunately, like the forelimb, the distal parts of the hind limb are not pictured in the 3-D skeletal image. Again this is unexpected as they have relatively robust bones. The unusual morphology of the hind limb, with the large triangular patella and expanded tibia is more clearly visible in the X-ray than the CT scan images. Like the carpus of the forelimb, the small bones of

the pes are highly modified and difficult to identify even from X-ray images. However, it is interesting to note that the clawed digits of the foot are splayed, and held in a somewhat abducted and medially rotated posture, presumably to achieve the maximum surface area of the sole of the foot when burrowing.

Soft Tissue Structure

From all MRI views (Figure 3), the most apparent soft-structure is a large amount of subcutaneous fat on this specimen, particularly around the ventral surface of the pelvis but also dorsal to the pelvis and anteriorly around the shoulders. This very large amount of fat appears as a high signal intensity on the magnetic resonance images. Upon dissection, there was approximately four grams of subcutaneous fat – more than 10% of a 35 gram animal.

The largest organs of the digestive system, the liver, stomach and intestine, are easily distinguished. The abdominal cavity appears as very low signal intensity, oval-shaped structure in the mid-region of the animal, due to this space being air-filled as a result of an incision made in the skin for the penetration of formalin/alcohol for fixation of the internal organs. The liver is the most anterior organ of the abdomen, and multi-lobed in structure. The stomach appears quite dark on the left side of the abdominal cavity in the coronal sections. Also seen from CT scans, the stomach contains a large amount of sand resulting in the low signal intensity in MRI. The intestine fills the rest of the abdominal cavity and has a higher signal intensity than the stomach and liver. The smaller organs of the abdominal cavity, spleen, gall bladder, *etc* are not distinguishable. The oral cavity is also visible in the relevant coronal sections (Figure 3).

In the thoracic cavity, the heart is the only portion of the circulatory system that is clearly apparent in MRI. At particular levels of contrast it is possible to discern the chambers of the heart. Of the respiratory system the lungs are visible. Their triangular shape is best observed from the coronal sections (Figure 3).

The urinogenital system is poorly represented in the MRI due to the small size of these organs; only the testes are clear (in all views) and the kidneys in sagittal view. Posteriorly, lying in the mass of fat under the pelvis, the testes are seen very clearly, with good contrast between gonadal tissue and fat. It is difficult to assess the sex of marsupial moles externally as males have abdominal testes, so MRI provides a non-intrusive method for confirming that this specimen is male.

The brain is the only obvious component of the nervous system in the MRI images (Figure 3). With the MRI having a slice size of 1.4 mm, it is possible that the spinal cord was missed altogether in coronal and sagittal sections.

The hard, bony structures of the skeletal system appear dark on the MRI. Clearly visible are sections through the skull, vertebral column, ribs, humeri and femora. The large size of the vertebrae is obvious and it is easier to distinguish adjacent vertebrae in MRI than CT scans. Surrounding the long bones of the limbs, the major muscle groups are visible, but distinction between individual muscles is not possible except for the very large muscles of the thigh, upper arm and base of the tail. In these areas the muscle bulk is enormous, much greater than for non-fossorial mammals of comparable size (*personal observations*). The extensive muscles attaching to the tail are quite unusual and would seem to be related to the strengthening of the caudal vertebrae as noted from the CT skeletal images. The muscles of the tail also appear to be more strongly developed ventrally (for flexion) than dorsally (for extension).

In summary, traditional X-rays provide detail of skeletal elements but are sometimes difficult to interpret because a three dimensional structure has been projected onto a two dimensional image. Reconstruction of CT scans results in a three dimensional image that reduces the problem of overlap. Also, with the CT skeletal reconstruction, it is possible to rotate the image to obtain the desired view, an impossible manipulation with X-ray images. MRI provides information of the anatomy of soft tissue structures by recording the differential contrast of the various soft tissues. Due to the small size of the marsupial mole, detail in sections was at the resolution of the MR scanner. Nevertheless, some valuable information concerning the 3-D arrangement of the soft anatomy is apparent.

ACKNOWLEDGEMENTS

We are grateful to Ms Norah Cooper and Dr Ken Aplin of the Western Australian Museum for the loan of the specimen, and the X-ray images.

REFERENCES

Chapman, R. N. (1919). A study of the correlation of the pelvic structure and the habits of certain burrowing mammals. *American Journal of Anatomy* **25**: 185–219.

Gambaryan, P. and Kielan-Jaworowska, Z. (1997). Sprawling versus parasagittal stance in multituberculate mammals. *Acta Palaeontologica Polonica* **42**(1): 13–44.

Hildebrand, M. (1988). *Analysis of vertebrate structure* (third edition). John Wiley and Sons, Inc. New York.

Rogers, S. W. (1999). *Allosaurus*, crocodiles and birds: evolutionary clues from spiral computed tomography of an endocast. *Anatomical Record* **257**(5): 162–173.

Romagnano, A., Shiroma, J. T., Heard, D. J., Johnson, R. D., Sheiring, M. R., and Mladinich, C. (1996). Magnetic resonance imaging of the brain and coelomic cavity of the domestic pigeon (*Columba livia*

domestica). *Veterinary Radiology and Ultrasound* **37**(6): 431–440.

Samii, V. F., Biller, D. S., and Koblik, P. D. (1999). Magnetic resonance imaging of the normal feline abdomen: an anatomic reference. *Veterinary Radiology and Ultrasound* **40**(5): 486–490.

Slijper, E.J. (1946). Comparative biologic-anatomical investigations on the vertebral column and spinal musculature of mammals. Koninklijke Nederlandsche Akademie van Wetenschappen., Verhandelingen (Tweede Sectie) **42**: 1–128.

Stirling, E. C. (1891). Description of a new genus and species of Marsupialia, *Notoryctes typhlops*. *Transactions of the Royal Society of South Australia* **14**: 154–187.

Thomas, O. (1920). *Notoryctes* in north-west Australia. *Annals and Magazine of Natural History (9)* **6**: 111–113.

Thompson, G. G., Withers, P. C. and Seymour, R. S. (2000–2001). Blind diggers in the desert. Nature Australia (Summer) 26–31.

Withers, P. C., Thompson, G. G. and Seymour, R. S. (2000). Metabolic physiology of the north-western marsupial mole, *Notoryctes caurinus* (Marsupialia: Notoryctidae). Australian Journal of Zoology **48**: 241–258.

Manuscript received 6 November 2002; accepted 9 June 2003

Records of the Western Australian Museum **22**: 9–16 (2003).

Description of *Volutoconus hargreavesi calcarelliformis* subsp. nov. (Mollusca: Volutidae) from northwestern Australia

Fred E.Wells and Hugh Morrison
Department of Aquatic Zoology
Western Australian Museum
Perth, Western Australia 6000, Australia

Abstract – *Volutoconus hargreavesi calcarelliformis* subsp. nov. is described from the outer continental shelf off Port Hedland, northwestern Australia. The new subspecies is compared with *V. hargreavesi hargreavesi* (Angas, 1872), and *V. hargreavesi daisyae* Weaver, 1967, which is recognised as a valid subspecies.

Keywords: Subspecies, volute, *Volutoconus*, Gastropoda, Volutidae, Western Australia

INTRODUCTION

The volute genus *Volutoconus* is a small group of five species which are restricted to northern Australia, adjacent areas of the east and west coasts of the continent, and eastern Indonesia. The type species, *V. coniformis* (Cox, 1871), occurs along the north coast of Western Australia from the Dampier Archipelago to the west Kimberley. Further north, *V. bednalli* (Brazier, 1878) extends across the north Kimberley to Torres Strait, Queensland and throughout the Timor Sea to eastern Indonesia, including Irian Jaya. *Volutoconus grossi* (Iredale, 1927) ranges southward along the east coast of Australia from Townsville, Queensland to Port Macquarie, New South Wales. Two subspecies are generally recognised: *V. grossi grossi* (Iredale, 1927), which occurs south from Keppel Bay, Queensland and *V. grossi mcmichaeli* Habe and Kosuge, 1966, which occurs further north in the Townsville area. The fourth species, *V. hargreavesi* Angas, 1872, occurs widely along the west coast of Western Australia, from Mandurah to North West Cape, and along the north coast as far as the western Kimberley. Another species, *V. capricorneus*, was described by Wilson (1972) from west of Point Cloates and provisionally placed in *Volutoconus*. The generic placement of the species has varied, but the most recent analysis (Willan, 1995) places it in *Volutoconus*.

Weaver (1967) described a geographical variant of *Volutoconus hargreavesi* as the subspecies *V. hargreavesi daisyae*, which occurs along the west coast of Western Australia from North West Cape south to about Mandurah. Weaver restricted the nominate subspecies, *V. hargreavesi hargreavesi*, to the north coast of the state. However, Weaver and DuPont (1970) subsequently reported that further collecting had narrowed the gap between the two forms, and that subspecies status was not justified. Wilson and Gillett (1971) retained the separation of the subspecies, but stated that the finding of intermediates might show that the separation was not warranted. Wilson (1994) later considered that there was no need to separate the two subspecies. Poppe and Goto (1992) separated the two, but as forms, which have no taxonomic standing.

Recent curation of the volutes in the collection of the Western Australian Museum has uncovered a deep-water subspecies in the *V. hargreavesi* complex, which is described here. In addition, *V. hargreavesi daisyae* is recognised as a valid subspecies.

Institutional acronyms: AMNH, American Museum of Natural History; DMNH, Delaware Museum of Natural History; NTM, Northern Territory Museum, WAM, Western Australian Museum.

SYSTEMATICS

Family Volutidae

Genus *Volutoconus* Crosse, 1871

Volutoconus Crosse, 1871: 306

Type species

Voluta coniformis Crosse, 1871, by original designation.

Diagnosis

(Adapted from Weaver and DuPont [1970]). Moderately large (60 to 130 mm) volutes, solid, with a range of colour patterns. Spire variable, elevated

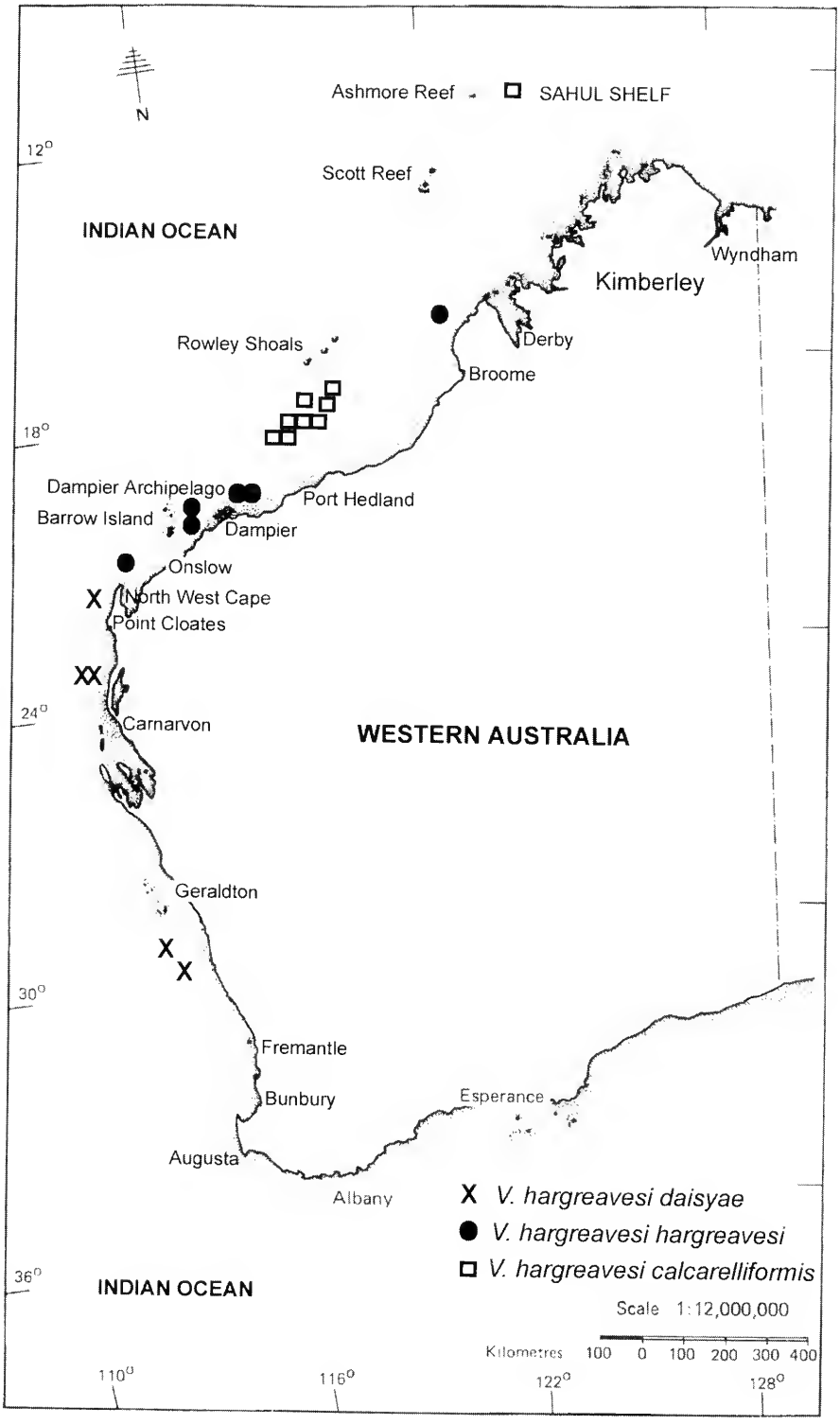


Figure 1 Distribution of *Volutoconus hargreavesi calcarelliformis* subsp. nov., *V. hargreavesi hargreavesi* (Angas, 1872), and *V. hargreavesi daisyae* Weaver, 1967.

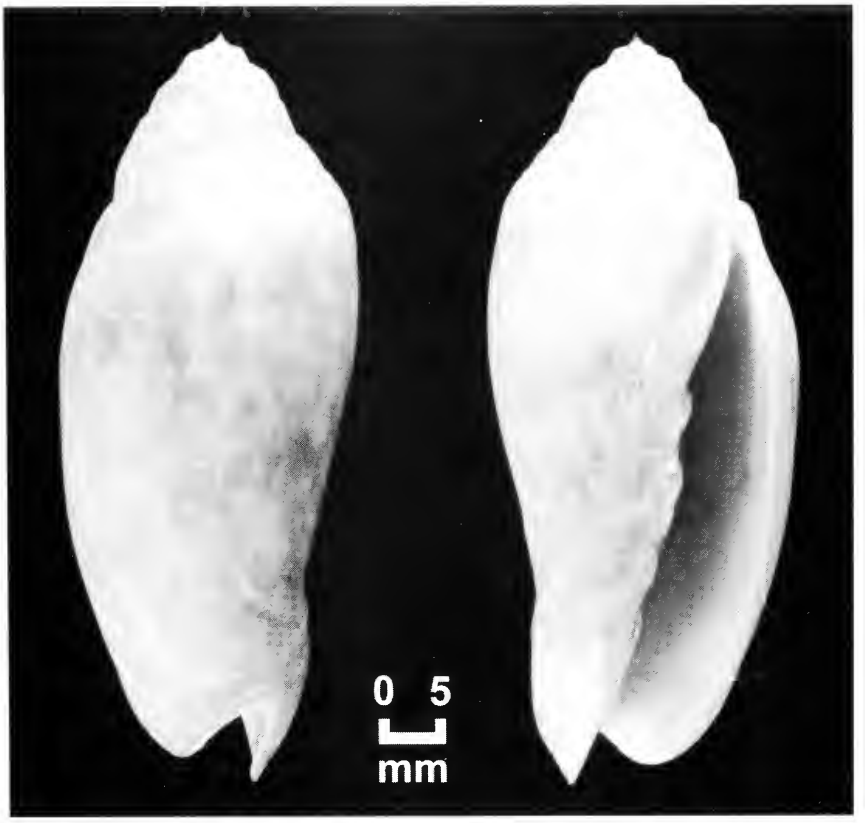


Plate 1 Holotype of *Volutoconus hargreavesi calcarelliformis* subsp. nov. (WAM S 14359)

or depressed. Protoconch smooth or radially ribbed, usually possessing a sharp apical spire (calcarella). Columella with four or more plaits. Periostracum and operculum absent. Radula (where known) uniserial, with large, tricuspid teeth, cusps strongly arched and fang like, median cusp much longer than laterals.

Remarks

The genus is restricted to northern Australia and Indonesia, ranging over the entire northern coastline of the continent, with individual species extending down both the west and east coasts. The systematics of *Volutoconus* have been examined in detail by Abbott (1958); McMichael (1960); Weaver (1967); Weaver and duPont (1970); Wilson and Gillett (1971); Wilson (1972; 1994) and Poppe and Goto (1992). The genus occurs from intertidal areas to at least 200 m. Fossils previously included in the genus were considered to belong to *Nannamoria* by Darragh (1988). Darragh recorded only a single fossil specimen of an unidentified *Volutoconus*, which he considered to closely resemble *V. hargreavesi*.

***Volutoconus hargreavesi hargreavesi* (Angas, 1872)**
Plates 2c, 3c, Figure 1

Voluta hargreavesi Angas, 1872: 613–614, plate 42, figure 13 (locality unknown); Weaver, 1960: 1, 3 front page plate (4 shells on left); Weaver, 1967: 302, 304, plate 41, figures 1–4, map; Weaver and duPont, 1970: 138, plate 61E–F; Matsukuma *et al.*, 1991: p. 99, plate 97, figure 3; Poppe and Goto, 1992: 212, plate 107, figures 3–5, 7.

Cymbiola (*Volutoconus*) *hargreavesi* (Angas): Abbott, 1958: 4

Volutoconus hargreavesi hargreavesi (Angas): Wilson and Gillett, 1971: 74, plate 49, figure 5.

Type material

Location of type unknown.

Weaver (1967) states the holotype is lodged in the American Museum of Natural History, number AMNH 8304. Weaver & DuPont (1970) questioned whether this is in fact the holotype as there are differences between the colour pattern on the shell and the illustration.

The published catalogue of the AMNH (Boyko and

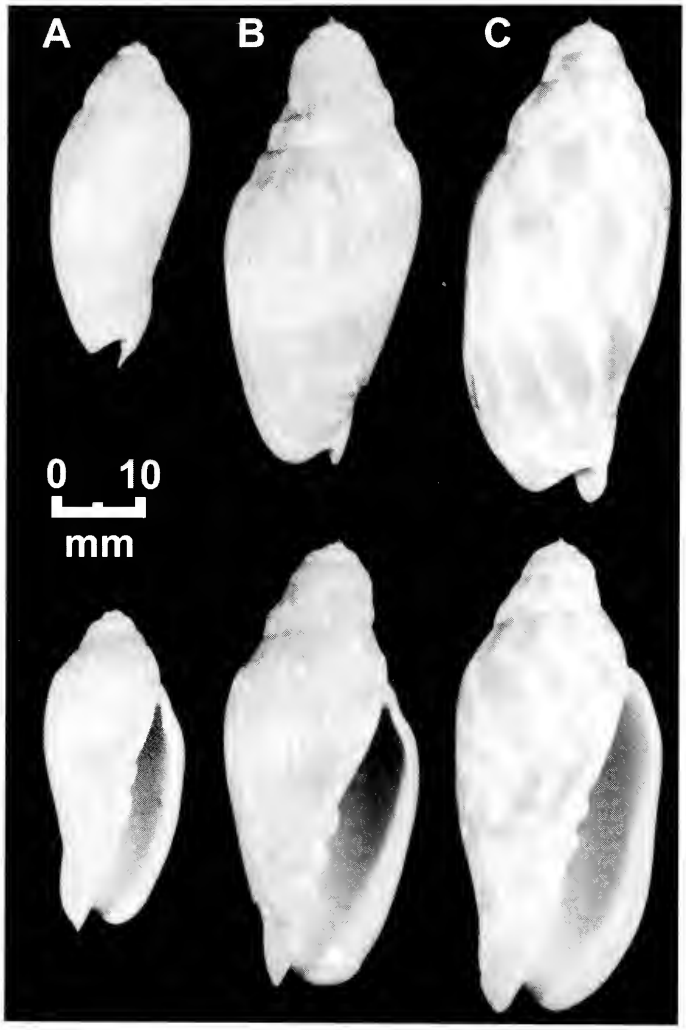


Plate 2 Comparison of shells of *Volutoconus hargreavesi*. a. Holotype of *V. hargreavesi calcarelliformis* subsp. nov. (WAM S 14359). b. *V. hargreavesi daisyae* Weaver, 1967 (WAM S 14358). c. *V. hargreavesi hargreavesi* (Angas, 1872) (WAM S 14348).

Cordeiro, 2001) states: "AMNH 8304. ex Steward Collection #1971. Richards and Old (1969: 117) summarized the limited information about this shell. They noted that it did not match exactly the size given by Angas (1872) for his unique specimen. AMNH 8304 is the same size as the figure of the shell in Angas (1872: plate 42, figure 13) and matches the description. However, the AMNH shell is much more worn than suggested by Angas's (1872) figure, and the color pattern is quite different. Based on the available evidence, we are inclined to consider AMNH 8304 an old specimen of this taxon, but we think its holotype status is unlikely."

Type locality

Angas (1872) did not provide a type locality for *V. hargreavesi*. Weaver (1960) subsequently designated Bedout Island in the Dampier Archipelago as the type locality.

Material examined: Australia: Western Australia: WAM S 14348, 2 specimens, NW of Roebuck Bay, S of Lacepedes Island (16°52'S; 122°08'E); WAM S 14349, 1 specimen, off Cape Lambert (20°36'S; 117°10'E); WAM S 14350, 1 specimen, 26 m, Dampier Archipelago, approximately 18 km W of Eaglehawk Island, (20°39'S;116°18'E); WAM S 14351, 1 specimen, 97 m, Onslow, 13 km N of Long Island (20°55'S;115°51'E); WAM S 14352, 1 specimen, no data (seized by Australian Customs); WAM S 12669, 1 specimen, 103 m, North West Cape (21°36.22'S; 114°11.11'E), on sand and mud.

Diagnosis

Calcarella small, orange colour, very finely ribbed. First two whorls of teleoconch white with very fine axial ribbing. Upper whorls with very fine ribbing. Body whorl with distinct, but fine ribbing. Colour variable, mottled orange and white, generally with 2 indistinct bands, one on shoulder of body whorl, one at base of whorl, sometimes a third intermediate band is present at base of body whorl. Four high, narrow columellar plaits. Anterior canal with deep notch, margin raised. Interior pale fawn to white.

Range

North West Cape to west Kimberley, Western Australia

Depth range

Intertidal to about 100 m.

Animal

Not known.

Remarks

The three subspecies of *V. hargreavesi* are geographically distinct (Table 1). The nominate subspecies, *V. hargreavesi hargreavesi*, occurs along the continental coastline, from about North West Cape to the west Kimberley. Most specimens are from shallow water, but there are two lots in the WAM from about 100 m. *Volutoconus hargreavesi daisyae* occurs further to the south, along the west coast of Western Australia, from about Mandurah to North West Cape, in depths of 40 to 134 m. There is an area at North West Cape where the species ranges may or may not overlap. In contrast, *V. hargreavesi calcarelliformis* lives in deeper waters (150–202 m) on the North West Shelf from the Rowley Shoals to Cartier Island.

Compared to *V. hargreavesi calcarelliformis*, *V. hargreavesi hargreavesi* has a smaller calcarella for the size of the shell. The shell of *V. hargreavesi hargreavesi* is bigger with a smoother surface. *Volutoconus hargreavesi hargreavesi* differs from *V. hargreavesi daisyae* in being a broader shell with fine growth lines instead of the more pronounced ribs found on *V. hargreavesi daisyae*.

Volutoconus hargreavesi daisyae **Weaver, 1967**
Plates 2b, 3b

Volutoconus "species" Angas, Weaver, 1960: 1, 3 front page plate (large centre shell).

Volutoconus hargreavesi daisyae Weaver, 1967: 302, 304, plate 41, figures 5–9, map; Wilson and Gillett, 1971: 74, plate 49, figure 6.

Volutoconus hargreavesi (Angas): Weaver and duPont, 1970: 138, plate 61G; Poppe and Goto, 1992: 212, plates 106, figure 1,2; Wells and Bryce, 1986: 118, figure 456; Wilson, 1994: 118, plate 21, figure 4 a–e.

Type material

Holotype, DMNH 10022.

Type locality

Southwest of North West Cape, central Western Australia, 22°00'S; 113°45'E.

Material Examined

Australia: Western Australia: WAM S 14355, 1 specimen, 134 m, NW of Shark Bay (23°39'S; 113°11'E); WAM S 14356, 1 specimen, 134 m, NW of

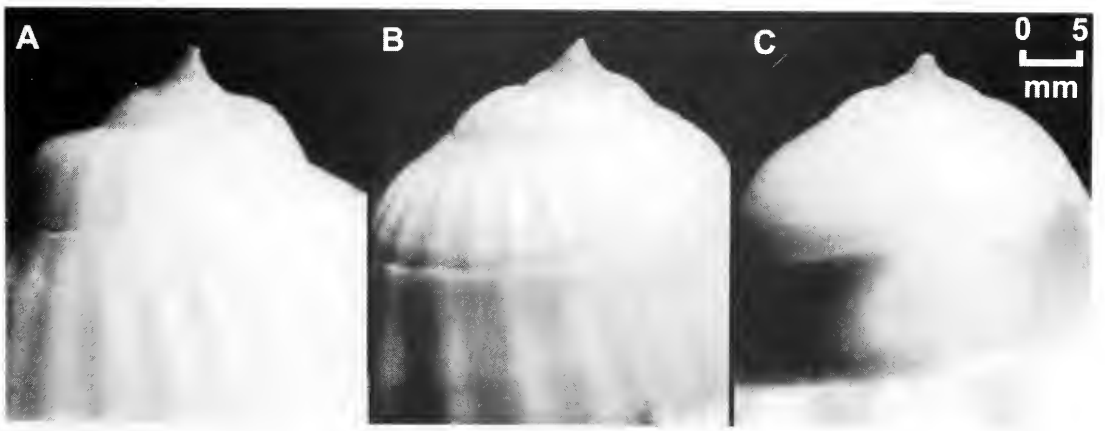


Plate 3 Comparison of protoconchs of *Volutoconus hargreavesi*. a. Holotype of *V. hargreavesi calcarelliformis* subsp. nov. (WAM S 14359). b. *V. hargreavesi daisyae* Weaver, 1967 (WAM S 14358). c. *V. hargreavesi hargreavesi* (Angas, 1872) (WAM S 14348).

Shark Bay (23°39'S; 113°11'E); WAM S 14357, 1 specimen, 110 m, 92 km W of Dongara (29°07.5'S; 113°57.4'E), sponges and stone rubble; WAM S 14358, 1 specimen, off Greenhead (30°04'S 114°58'E).

Diagnosis

Calcarella small, orange colour. Shell fusiform. First two whorls of teleoconch white with strong axial ribbing. Upper whorls with very strong ribbing extending onto body whorl. Body whorl heavily ribbed. Colour variable, mottled orange and white with 2 indistinct bands, one on upper body whorl, one lower on whorl. Four high, narrow columellar plaits. Anterior canal with deep notch, margin raised. Interior pale fawn to white.

Range

West coast of WA; Mandurah to North West Cape, Western Australia

Depth

Approximately 40 m to 134 m.

Animal

Not known.

Remarks

Volutoconus hargreavesi daisyae differs from *V. hargreavesi hargreavesi* in having a narrower shell with pronounced axial ribbing instead of the fine growth lines found on *V. hargreavesi hargreavesi*. *Volutoconus hargreavesi daisyae* differs from *V. hargreavesi calcarelliformis* in being longer, more robust, with a similar protoconch, but a brighter orange colour. The ribs of *V. hargreavesi daisyae* are much heavier.

Volutoconus hargreavesi calcarelliformis subsp. nov.

Plates 1, 2a and 3a

Holotype

WAM S 14359, 150–160 m, 239 km NE of Cape Lambert (18°42.8'S; 118°03.2'E), Western Australia, Australia, sand, rubble and dead shells, collected by L.M. Marsh *et. al.* on 18 August 1995.

Paratypes

Australia: Western Australia: WAM S 14360, 6 specimens, 173–193 m, 70 km S of Cunningham Island, Imperieuse Reef, Rowley Shoals (18°06.9'S; 118°56.7'E), sand, rubble and dead shells; WAM S 14361, 5 specimens, 150–160 m, 239 km NE of Cape Lambert (18°42.8'S; 118°03.2'E), rubble and dead shells; WAM S 14362, 1 specimen, 150–160 m, 239 km NE of Cape Lambert (18°38.6'S; 118°07'E), sand, rubble and dead shells; WAM S 14363, 2 specimens, 154 m, 184 km N of Port Hedland (18°47'S; 117°58'E), grey mud and shell rubble; WAM S 14364, 2 specimens, 154 m, 184 km N of Port Hedland (18°47'S;117°58'E), grey mud and shell rubble; WAM S 14365, 1 specimen, 201–202 m, 217 km N of Port Hedland (18°20.5'S; 118°27.7'E), grey mud; WAM S 14389, 1 specimen, 150–160 m, 239 km NE of Cape Lambert (18°42.8'S 18°39.6'S), sand rubble and dead shells. NTM P8581, 1 specimen, 180 m, 20 km south of Barracouta Shoal, west of Cartier Reef, Sahul Shelf (12°42.86'S; 123°57.98'E), coarse broken shell substrate; Mike Claydon private collection, 1 specimen, trawled by scampi boats, on sand mud and shell, 220 m, NW of Point Samson.

Description

Calcarella prominent, tall, smooth sided, lacking axial ribbing. Bright orange colour. First two whorls of teleoconch white, with strong axial ribbing. Lower whorls also heavily ribbed with mottled fawn to orange patterning. Body whorl finely ribbed, mottled brown with 3 faint bands, one below suture, one on outer body whorl, one lower on whorl. Four high, narrow columellar plaits. Anterior canal with deep notch. Interior white, some shells with pale fawn to white on inside of outer lip.

Shell measurements

Table 1 shows the measurements of the type series.

Geographical range

North West Shelf, Western Australia, from about Rowley Shoals to Cartier Island.

Depth

150–202 m.

Animal

Not known.

Etymology

Named after the distinctive calcarella at the apex of the shell spire.

Remarks

The key feature of *Volutoconus hargreavesi calcarelliformis* is the prominent size of the calcarella for the size of the shell. It differs from *V. hargreavesi hargreavesi* in being smaller, with fine ribbing, strongly ribbed protoconch, and it lives in slightly deeper water. *Volutoconus hargreavesi hargreavesi* has a smoother shell with fine growth lines. *Volutoconus hargreavesi calcarelliformis* differs from *V. hargreavesi daisyae* in being shorter, more robust, with a similar protoconch, but a brighter orange colour. The ribs

Table 1 Comparison of shell characteristics of *Volutoconus hargreavesi hargreavesi* (Angas, 1972), *V. hargreavesi daisyae* Weaver, 1968, and *V. hargreavesi calcarelliformis* subsp. nov.

Species	Range		Protoconch	Teleoconch Sculpture	Plaits on Columella	Shell measurements			
	Geographic	Depth (m)				N	Length (mm) Mean ± 1 S.E.	Width (mm) Mean ± 1 S.E.	Length/ Width Mean ± 1 S.E.
V. hargreavesi hargreavesi (Angas, 1872)	North coast of WA; North West Cape to west Kimberley	0-201	Small calcarella, orange colour, finely ribbed.	Shell broad, first two whorls of teloconch white with with very fine axial ribbing. Upper whorls with very fine ribbing. Body whorl with distinct, but fine ribbing. Colour variable, mottled orange and white, generally with 2 indistinct bands, one on shoulder of body whorl, one at base of whorl, sometimes a third intermediate band is present at base of body whorl. Four high, narrow columellar plaits. Anterior canal with deep notch, margin raised. Interior pale fawn to white.	4 high, narrow	5	18-105 63 ± 15	8-37 25 ± 6	2.17-2.84 2.48 ± 0.12
V. hargreavesi daisyae Weaver, 1968	West coast of WA; Mandurah to North West Cape	0-134	Small calcarella, orange colour	Shell fusiform. First two whorls of teloconch with strong axial ribbing, white. Upper whorls with very strong ribbing extending onto body whorl. Colour mottled orange and white. Body whorl heavily ribbed. Colour variable, mottled orange and white with 2 indistinct bands, one on outer body whorl, one lower on whorl. Anterior canal with deep notch, margin raised. Interior pale fawn to white.	4 high, narrow	3	76-78 77 ± 1	28-32 30 ± 1	2.38-2.78 2.61 ± 0.12
V. hargreavesi calcarellaformis subsp. nov.	North West Shelf, W.A.	150-202	Tiny calcarella, smooth sided, tall, lacks axial ribbing. Bright orange colour.	First two whorls of teloconch with strong axial ribbing, white. Lower whorls also heavily ribbed with a mottled fawn to orange patterning. Body whorl finely ribbed, mottled brown with 3 faint bands, one below suture, one on outer body whorl, one lower on whorl. Anterior canal with deep notch. Interior white, some with pale fawn to white on inside of outer lip.	4 high, narrow	14	38-64 50 ± 2	16-26 21 ± 1	2.14-2.94 2.41 ± 0.05

of *V. hargreavesi daisyae* are much stronger than those of *V. hargreavesi calcarelliformis*.

The dwarf form of *V. grossi* (Iredale, 1927) from deep water off the Great Barrier Reef, Queensland, is very similar to *V. hargreavesi calcarelliformis*. Further material is required before the relationships between *V. grossi* and *V. hargreavesi* can be fully understood. In addition to the considerable geographic separation with a shallow water barrier between them, dwarf specimens of *V. grossi* can be separated from *V. hargreavesi calcarelliformis* by having a narrower shell and finer ribbing, and white calcarella.

ACKNOWLEDGEMENTS

We are grateful to Dr Richard Willan for information on the new subspecies, and Mike Claydon for the loan of material of the new subspecies. Clay Bryce was kind enough to photograph the specimens. We are pleased to acknowledge discussions with Dr Patrice Bail, Glad Hansen, Alan Limpus, and Dr Barry Wilson. Corey Whisson databased the specimens and assisted with preparation of the figure and plates. Drs Tom Darragh and Richard Willan very kindly reviewed the maunscript.

REFERENCES

Abbott, R.T. (1958). Notes on the anatomy of the Australian volutes, *bednalli* and *grossi*. *Journal of the Malacological Society of Australia* **1**(2): 2–7.

Angas, G.F. (1872). Description of a new species of *Volnta*. *Proceedings of the Zoological Society of London* **1872**: 613–614.

Boyko, C.B. and Cordeiro, J. (2001). Catalog of Recent Type Specimens in the Division of Invertebrate Zoology, American Museum of Natural History. V. Mollusca Part 2 (Class Gastropoda [exclusive of Opisthobranchia and Pulmonata], with Supplements to Gastropoda [Opisthobranchia], and Bivalvia). *Bulletin of the American Museum of Natural History* **262**: 1–170.

Brazier, John. (1878). Descriptions of seven new species of terrestrial and marine shells from Australia. *Proceedings of the Zoological Society of London* **1878**: 20–23.

Cox, J.C. (1871). Description de deux espèces novelles de *Volnta* et observations sur le *V. punctata* Swainson. *Journal de Conchyliologie* 3(**19**): 74–77.

Crosse, J.C.H. (1871). Distribution géographique et catalogue des espèces actuelles du genre *Volnta*. *Journal de Conchyliologie* **14**: 105–117.

Darragh, T.A. (1988). A revision of the Tertiary Volutidae (Mollusca: Gastropoda) of south-eastern Australia. *Memoirs of the Museum of Victoria* **49**: 195–307.

Iredale, T. (1927). Caloundra shells. *The Australian Zoologist* **4**: 336.

McMichael, D.F. (1960). Notes on some Australian Volutidae. *Journal of the Malacological Society of Australia* **1**(4): 4–13.

Matsukuma, A., Okutani, T., and Habe, T. (1991). *World Seashells of Rarity and Beauty*. National Science Museum, Tokyo.

Poppe, G.T. and Goto, Y. (1992). *Volutes*. Mostra Mondiale Malacologia, Cupra Marittima (AP- Italy).

Richards, M.C. and Old, W.E. Jr. (1969). *A catalogue of molluscan type specimens in the Department of Living Invertebrates, the American Museum of Natural History*. American Museum of Natural History, New York. Unpublished report, 147 pp.

Weaver, C.S. (1960). Hawaiian scientific expedition finds rare Australian volutes. *Hawaiian Shell News* **8**(10): 1,3.

Weaver, C.S. (1967). A new subspecies of *Volutoconus hargreavesi* (Angas, 1872) from central Western Australia. The Veliger **9**(3): 301–304.

Weaver, C.S. and duPont, J.E. (1970). *The Living Volutes. A monograph of the Recent Volutidae of the world*. Delaware Museum of Natural History, Monograph Series No. **1**: 1–375.

Wells, F.E. and Bryce, C.W. (1986). *Seashells of Western Australia*. Western Australian Museum, Perth.

Willan, R.C. (1995). Taxonomic and biogeographic review of the Australian endemic genus *Nannamoria* (Gastropoda: Volutidae) with the description of a new bathyal species. *Invertebrate Taxonomy* **9**: 107–113.

Wilson, B.R. (1972). New species and records of Volutidae (Gastropoda) from Western Australia. *Journal of the Malacological Society of Australia* **2**(3): 339–360.

Wilson, B.R. (1994). *Australian Marine Shells*. Volume 2. Odyssey Publishing, Kallaroo, Western Australia.

Wilson, B.R. and Gillett, K. (1972). *Australian Shells*. A.H. and A.W. Reed, Sydney.

Manuscript received 29 April 2003; accepted 29 July 2003

Records of the Western Australian Museum **22**: 17–22 (2003).

A new genus and species of trigoniuline milliped from Western Australia (Spirobolida: Pachybolidae: Trigoniulinae)

Richard L. Hoffman
Virginia Museum of Natural History
Martinsville, Virginia 24112, USA

Abstract – A new genus and species, *Austrostrophus stictopygus*, is described from northern Western Australia. The presence of punctate paraprocts, very rare in spiroboloid diplopods, is shared with *Ainigmabolus chisholmi* of New South Wales, but apparently only as a homoplasic condition.

INTRODUCTION

Whether considered a subfamily of the Pachybolidae or a discrete family, trigoniuline millipeds comprise a conspicuous element in the fauna of southeastern Asia and Indonesia, whence some 21 genera are currently recognized (Jeekel, 2001). The group is, however, only marginally represented in Australia, chiefly by *Zygostrophus* and *Ainigmabolus* on the eastern edge of the continent, and the recently described *Speleostrophus* (Hoffman, 1994) from an island on the west coast. The recent discovery of a highly disjunct new trigoniuline from Western Australia suggests that undercollecting along the western and northern periphery of the continent may account for this apparent poverty of Australian spiroboloids.

Family Pachybolidae Cook

Subfamily Trigoniulinae Attems

Austrostrophus gen nov

Type species
Austrostrophus stictopygus sp. nov.

Diagnosis
A trigoniuline genus characterized by the enlarged, distally excavate, gonopod coxae, into which the elongated, slender telopodites are basally recurved. Submarginal belt of paraprocts conspicuously set with large coarse punctures. Posterior edge of metazona with specialized fringe composed of small denticulate projections.

Distribution
Western Australia.

Etymology
A masculine neologism composed of the elements *austro* (from Latin *australis*, in allusion to the country of origin) + *-strophus*, a combining form employed in many generic names in this subfamily.

Austrostrophus stictopygus sp. nov.
Figures 1–10

Material examined
Male holotype (WAM T46241), from Western Australia: Burrup Peninsula, Rocky Hill at Hearson Cove (20°37'06"S, 116°47'05"E), R. Teale leg. 22 May 2002. Two immature females (WAM T46956) from the same locality, 30 September 2002, R. Teale and M. Maier, leg.

Diagnosis
With the characters of the genus.

Holotype
Adult male, length approximately 52 mm (broken), maximum diameter 4.2 mm. 51 segments + telson. Colour of recently preserved specimen: prozona grayish, mesozona piceous to black, metazona orange-brown. Mesozonal black pattern narrowed ventrad and absent above leg bases; antennae, legs, sterna and pleural region similar in colour to metazona.

Head without modifications, sides of genae slightly convex but convergent ventrad; interantennal and interocellarial widths 1.2 mm, ocellaria subrounded, maximum length 0.5 mm, about 36 ocelli in rows (4-5-7-6-6-5-3). 7+7 labral setae, 2+2 clypeal setae, those of each side widely separated. Antennae short, 2nd and 6th articles longest, similar in size and shape, 3rd–5th shorter and slightly more triangular in outline; outer distal ends of 5th and 6th articles with rounded, slightly convex sensory area, depigmented and appearing semimembranous; 7th article very short, with four terminal sensory cones. Mentum of

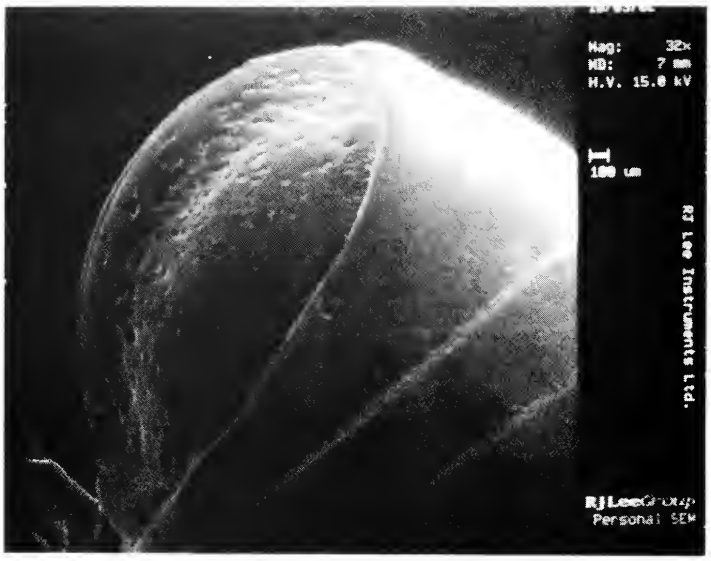


Figure 1 Posterior end of body, showing abbreviated form of the epiproct and coarsely punctate condition of the paraprocts (SEM x32).

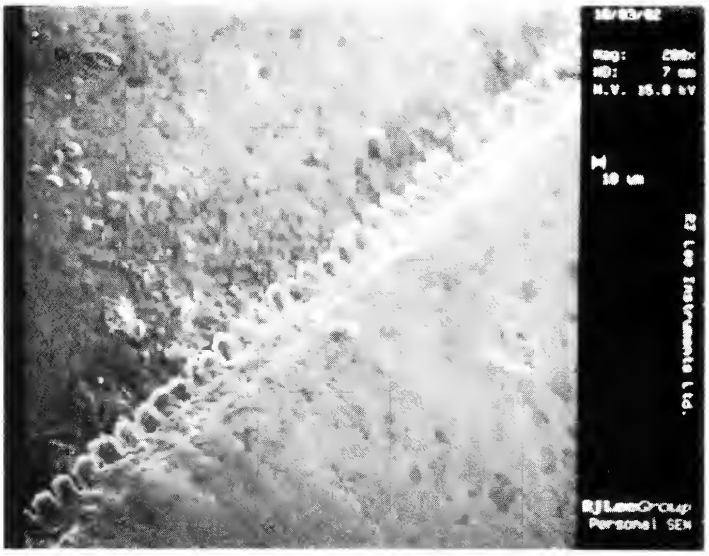
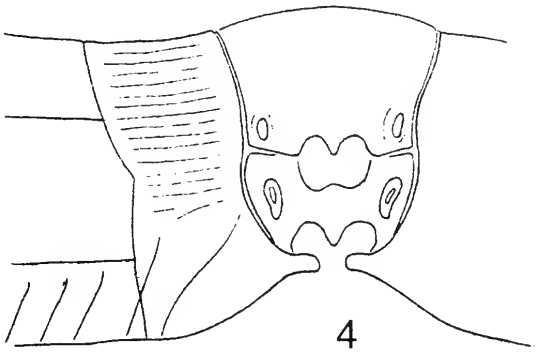
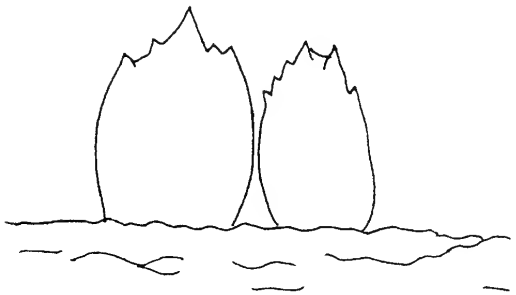


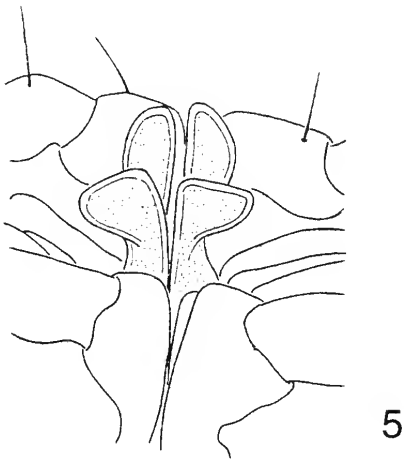
Figure 2 Posterior edge of metazonum showing the palaeate fringe (SEM x200).

gnathochilarium with low but distinct median ridge, prebasilar sclerite very thin. Mandibular bases without lobes or other modification.

Lateral ends of collum subtriangular as usual in this family; pleural region of 2nd segment produced ventrad and visible beneath end of collum as a digitiform lobe. Surface of collum and all body segments superficially smooth and polished: with magnification (60X) surface texture is a uniform isodiameteric mesh, on which is superimposed a pattern of longitudinal striations, prozona with several concentric striations below level of ozopores, curved posteriad at their ventral ends. Pores prominent, located in mesozona below level of lateral suture. Pleurotergal suture line visible; sterna subquadrate, smooth (Figure 4). Metazona slightly elevated above level of mesozona, and caudally decurved slightly, becoming much thinner and edged with a fringe composed of small separate, denticulate units (paleae) (Figures 2, 3).





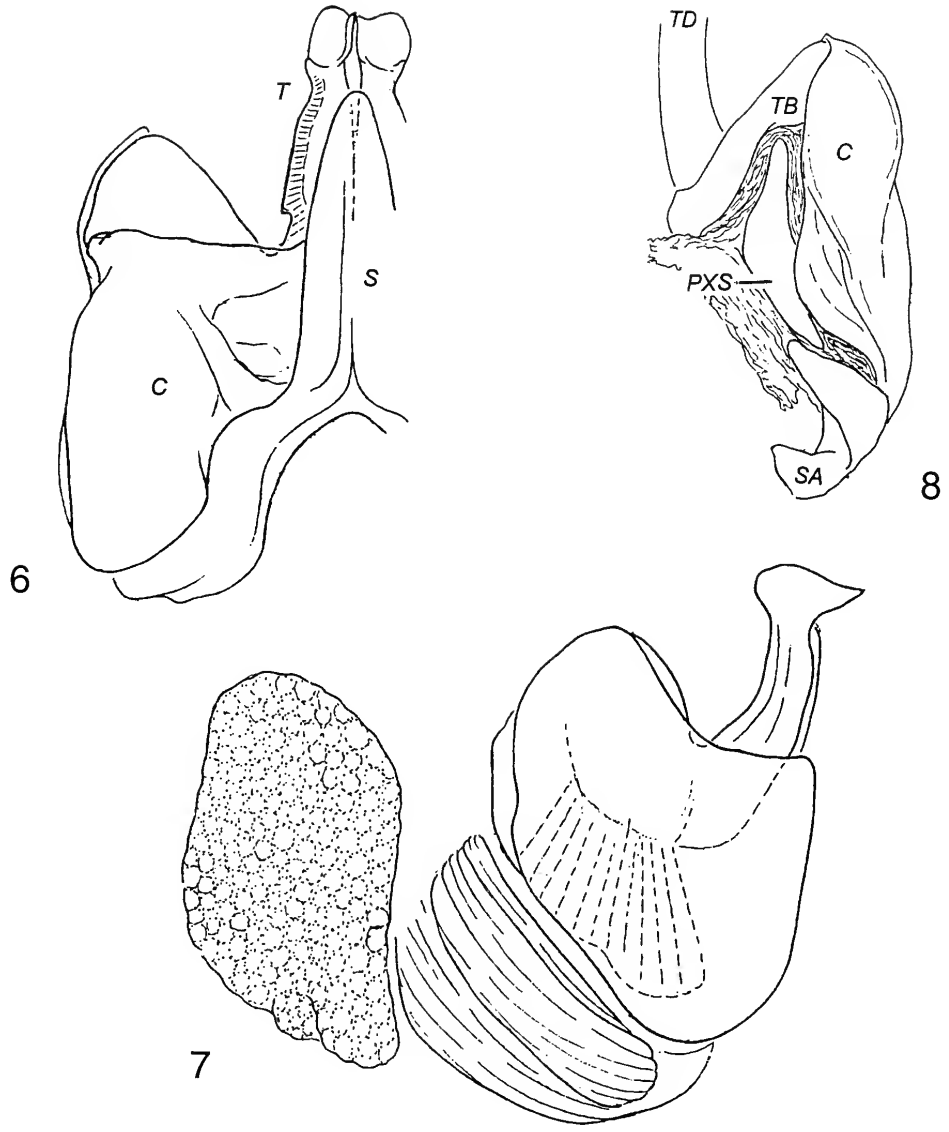


Figures 3–5 3. Two individual paleae, greatly enlarged (freehand, about 2000 x). 4. Sternal region of midbody segment, legs removed to show coxal sockets and partial closure of posterior sockets. 5. Bases of leg pairs 2–6, showing form of processes of 3rd and 4th coxae, posterior aspect.

Terminal segment (Figure 1) not produced dorsomedially; most of paraprocts visible in dorsal aspect, their posterior edge set off by a moderately deep, broad groove beset with numerous large coarse punctures, disk of paraprocts impunctate or nearly so. Hypoproct transversely narrow, unmodified.

Posterior coxal cavities partially closed by small median projection of sterna (Figure 4). Legs relatively long, tarsi visible in dorsal aspect when extended; length ratio of podomeres in descending order: 2-3-6-4-5-1. Podomeres essentially glabrous, basal four with a single small seta at distal end ventrally, postfemur with a distinctly larger seta in that position, tarsi typically with three large setae (nearly length of tarsal claw) in a ventrodistal row, and a single large supra-apical seta. Anterior legs without pads, although ventral surface of apical podomeres appears depigmented and less sclerotized than dorsal surface (perhaps endowed with moderate holding ability). Tarsal claws similar in size and shape to those of other legs. Coxae of legs 3 and 4 produced into conspicuous, flattened lobes, those of 4th coxa turned laterad apically (Figure 5).

Anterior gonopods distinctive in the globosely enlarged coxae, deeply excavate on mesal side, accommodating basal half of telopodites, anterior surface of coxae not produced into slender apices (Figure 6). Sternum modified "Y" shape, prolonged slightly behind coxae, sternal apodeme reflexed caudad and not visible in anterior aspect; posterior extension of sternum separated as a discrete elongate sclerite, narrowed at each end, and in contact with basal end of telopodite (Figure 8, PXS). Telopodite differing from typical trigoniuline structure in being attached to an elevated posterior rim of the coxa, then abruptly recurved into cavity of the latter, distal half reflexed ventrad behind median sternal projection as a slender stalk, apically



Figures 6–8 6. Left side of anterior gonopods, anterior aspect. S, sternum, C, coxa, T, telopodite. 7. Lateral aspect of gonopods (posterior pair concealed) with prostatic gland (stippled, at left) and retractor muscles of telopodite indicated by broken lines inside coxa. 8. Posterior view of left anterior gonopod, showing prolongation of coxa (C), with base (TB) and distal shaft (TD) of telopodite. PXS, posterior extension of sternum; SA, reflexed sternal apodeme.

capitate just beyond apex of sternal projection (Figures 7, 9).

Posterior gonopod (Figure 10) generally conforming to basic trigoniuline pattern: median sternal element (S) present, merging each side into a coalesced coxosternal region containing (1) a small chamber into which the prostatic duct (PD) discharges, and (2) a small, short, digitiform projection. Distal 2/3rds of gonopod (telopodite) set off at nearly a right angle by a deep flexible articulation (A). Prostatic groove courses on medial side to a clear membranous subapical lappet; form of telopodite and its various lobes and processes as shown in Figure 10.

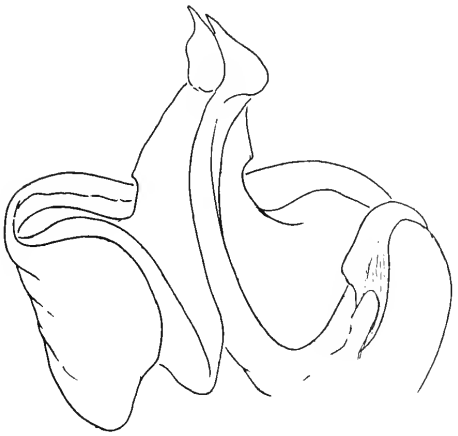


Figure 9 Oblique posteromedian aspect of gonopods to show the prominent flexure of the telopodites into the distal coxal cavity unique to this genus.

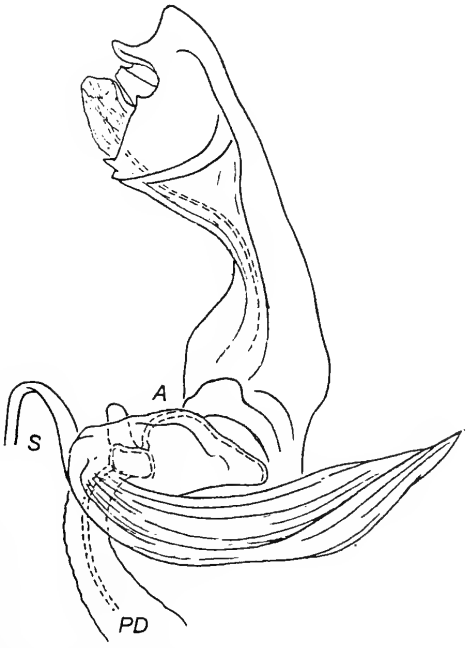


Figure 10 Posterior gonopod, lateral aspect, sternal apodeme concealed by the protractor and retractor muscles. PD, prostatic duct with its sclerotized internal tube. S, sternum; A, flexible articulation between coxal and telopodital regions.

Etymology

From the Greek *stiktos* (punctured) + *pygos* (rump), in allusion to the coarsely punctate paraprocts.

COMMENTS

Punctate paraprocts

My initial impression, confirmed by a preliminary literature survey and survey of material at hand, was that this character was not known for the entire order Spirobolida. Only through serendipity did I notice the remark by Verhoeff (1937: 149) that in *Ainigmabolus chisholmi* the *"Analklappen neben dem innenrande mit mehreren, unregelmassigen Eindrücken."* This species, a trigoniuline from New South Wales, shows virtually no similarities in gonopod structure with *A. stictopygus*, and apparently the paraproct modification must be considered a "geographic homoplasy" peculiar to Australia rather than any kind of synapomorphy for the two taxa.

Metazonal fringe

In many orders of Diplopoda the posterior edge of the metazona is provided with a thin, transparent, sclerotized membrane ("limbus"), variable both in width and ornamentation of its edge. The definitive treatment of limbus occurrence throughout helminthomorph Diplopoda (Schmidt, 1962), recorded that in the three "trigoniuline" families (Pachybolidae, Trigoniulidae, Spiromimidae) *"ein eigenlicher Limbus ist auch hier nicht vorhanden"* – at least in species of the six genera examined. In one, *Trigoniulus ceramicus*, the edge of the metazona itself is irregularly indented and darkly pigmented, but the typical limbus structure of a clear membrane with modified edge is in no way approximated. The condition in *Austrostrophus* is perhaps an elaboration of this simple form. The margin of the metazona is notably thinner than the sclerite otherwise, but is opaque and pigmented, no clear membrane is present, and the scale-like individual units (for which the term *paleae* is suggested, singular *palea*) of the fringe originate separately from the edge itself. Perhaps this expression could be distinguished by the name "paleate". In those taxa in which a true limbus is well-developed, e.g., Odontopygidae, the hyaline membrane itself can usually be removed intact as a continuous clear strip. In a general way, the true limbus seems to be best developed in taxa in which other character systems are clearly derived, and therefore indicative of an evolutionarily advanced status for such groups.

Gonopods

Although it seems generally appreciated that the

sperm transfer process in most helminthomorph diplopods is facilitated by a what is regarded as a prostatic secretion (with ?enzymatic, ?nutritive, ?buffering function) the glands themselves have not received a thorough comparative study. In Polydesmida, they lie in the coelom of segment 7 (often adjacent segments as well) and their secretion is conducted through the gonocoxae to a prostatic groove originating at the base of the telopodite. In Spirostreptida, the glands are generally located on the posterior side of and in close proximity to the gonocoxal folds. They have been scarcely noticed in Spirobolida, but their sclerotized ducts entering the bases of posterior gonopods are frequently illustrated. Because of the excellent state of preservation of the holotype of *A. stictopygus* I was able to determine that the glands are located in the 8th segment well behind the bases of the gonopods and each is nearly as large as the preceding gonocoxa (Figure 7). A long duct connects to the coxosternal region, the central sclerotized tube surrounded by a thick layer of what appears to be additional glandular tissue (Figure 10).

The function of the small internal chamber (*Spermagrube* of Verhoeff, 1937, Figure 13) remains unknown; it appears too small to be an effective reservoir. Some trigoniuline genera are credited with the presence of two such chambers.

Figure 8 shows the unique formation of the anterior gonocoxa in this genus. The posterior surface is greatly elongated distal instead of being short and basically transverse with the telopodite hinged along an exposed seam and apparently capable of very limited movement. In *Austrostrophus*, the base of the telopodite is only narrowly joined to the edge of the coxa, and apparently capable of being extended and retracted (Figure 7 shows retractor muscles only, I did not wish to locate the extensors by further dissection of the single specimen).

Relationships

As there remain a number of Papuasian trigoniuline genera of which the gonopod structure is unknown or only poorly known, I am unable to this time to suggest any candidate sister-group for *Austrostrophus*. The singular form of the anterior gonopods is not approached in any genus known to me, nor the presence of a modified metazonal edge. Curiously, the posterior gonopods offer no corresponding pecularities, and in fact these appendages tend to be conservatively quite similar through the subfamily.

ACKNOWLEDGEMENTS

I am very much indebted to my colleague Mark Harvey (WAM), who on realizing that a trigoniuline from Western Australia would be of particular interest, brought the specimen to my attention. I am much indebted to Dr. Harvey for the the opportunity to examine and describe this curious, disjunct spiroboloid, and to Patrick Brannon, VMNH technician, for the SEM photography.

REFERENCES

Jeekel, C. A. W. (2001). A bibliographic catalogue of the Spirobolida of the Oriental and Australian regions (Diplopoda). *Myriapod Memoranda* **4**: 5–103.

Hoffman, R. L. (1994). Studies on spiroboloid millipeds. XVIII. *Speleostrophus nesiotes*, the first known troglobitic spiroboloid milliped, from Barrow Island, Western Australia (Diplopoda: Pachybolidae: Trigoniulinae). *Myriapodologica* **3**: 19–24.

Schmidt, D. (1962). Über die taxionomische Wertigkeit von Strukturen des Metazonit-Hinterrandes bei Diplopoden. *Senckenbergiana biologia* **43**: 65–80.

Verhoeff, K. W. (1937). Ueber einige neue Diplopoden aus Australien. *Records of the Australian Museum* **20**: 133–149.

Manuscript received 11 November 2002; accepted 11 December 2002

Records of the Western Australian Museum **22**: 23–45 (2003).

Psammophilous halacarids (Halacaridae, Acari) from Dampier, Western Australia. Description of species and faunal comparison of the mesopsammal halacarid fauna of western and eastern Australia

Ilse Bartsch

Forschungsinstitut Senckenberg, c/o DESY, Notkestr. 31, 22607 Hamburg, Germany
e-mail bartsch@meeresforschung.de

Abstract – Twelve species of halacarid mites were extracted from tidal and subtidal sandy deposits and coral fragments in the tropical Dampier area, Western Australia. The genera and number of species (in parentheses) are: *Actacarus* (2), *Anomalohalacarus* (1), *Arhodeoporus* (1), *Copidognathus* (1), *Scapthognathides* (2), *Scapthognathus* (1), and *Simognathus* (4). All species are diagnosed and four species, new to science, are described, viz. *Actacarus festivus* sp. nov., *Anomalohalacarus dampierensis* sp. nov., *Simognathus salebrosus* sp. nov., and *Simognathus tener* sp. nov. Seven of the twelve species are known from the Indo-Pacific region, from warm-temperate Western Australia, tropical eastern coast of Australia, Hawaiian Islands, and/or off Chile.

Key words: Australia, marine mites, psammobionts, new species, faunal comparison

INTRODUCTION

Sandy deposits with medium and coarse grain fractions provide a system with a large surface, different-sized void volumes and regular interstitial water replenishment but shelter from extreme amplitudes of environmental parameters. These deposits contain a specialized fauna, the interstitial fauna or mesopsammon, terms introduced by Nicholls (1935) and Remane (1940).

The first records of mesopsammic halacarid species from Australia were from Rottnest Island, Western Australia, an island with a variety of sandy deposits. About 30 psammophilous halacarid mites from intertidal and subtidal sandy deposits have been described (Bartsch 1993). Otto (1999a, b, 2000a–e, g, 2001a–c), Otto and Bartsch (1999) and (Bartsch 2000) added more than 50 new records to the list of Australian species extracted from sandy deposits on the northeastern coast of Australia, many of them being psammophilous. Examination of both tidal and subtidal sediments collected near Dampier, tropical Western Australia, resulted in both new records and new halacarid species.

STUDY AREA, MATERIAL AND METHODS

Dampier, on the Burrup Peninsula, lies in the tropical north of Western Australia, at about 20°S, 117°E. The shoreline is characterized by rocky platforms, rocks and mangroves. Areas with sandy deposits with medium and coarse sand are rare. Subtidal deposits immediately off Dampier are rich in organic material and typical arenicolous halacarids are generally lacking, but around the outer islands of the Dampier Archipelago there are coarse sediments with a psammophilous meiofauna.

The mites were extracted from the sand by frequently stirring with water and decanting through a sieve with 100 µm mesh diameter. The mites were cleared in lactic acid and mounted in glycerin jelly. Type and voucher specimens are deposited in the Western Australian Museum, Perth (WAM).

Abbreviations used in the descriptions: AD = anterior dorsal plate; AE = anterior epimeral plate; ds-1 to ds-6 = first to sixth dorsal idiosomatic seta(e); GA = genitoanal plate; GO = genital opening; OC = ocular plate(s); P = palp, P-1 to P-4 = first to fourth palpal segment; pas = parambulacral seta(e); PD = posterior dorsal plate; PE = posterior epimeral plate(s); pgs = perigenital setae; sgs = subgenital setae. The legs are numbered I to IV, leg segments 1 to 6 are trochanter, basifemur, telofemur, genu, tibia, and tarsus.

Except one species recently described and figured on the base of specimens from Dampier (Bartsch 2003b), the species are diagnosed and illustrated, in general relying on individuals from the Dampier area. In the bibliography of a given species only the most relevant descriptive papers are cited.

SYSTEMATICS

Subfamily Actacarinae Viets, 1939

Genus *Actacarus* Schulz, 1937

Actacarus festivus sp. nov.
Figure 1A–H

Material Examined

Holotype

Female, sponge garden, West of Rocky Head, 20°32.1'S, 116°26.7'E, Enderby Island, Dampier Archipelago, Western Australia, Australia; 2–13 m, unsorted sandy deposits, 3 August 2000, coll. C. Bryce (WAM T52095).

Etymology

Specific name from festivus, Latin, nice, festive.

Diagnosis

Idiosomal length 205 µm. Dorsal and ventral plates uniformly porose. Opposing margins of AD and PD and AE and GA truncate. Length of PD less than twice that of AD. Setae ds-2 within striated Integument. PE with three setae; one pair of setae within striated integument. Anterolateral margins of GA converging. Ovipositor extending beyond GA. Gnathosoma 0.28 of length of idiosoma. Rostrum extending slightly beyond middle of P-2. Tectum arched. Tibia I with three slender ventral setae, tibiae II to IV each with one faintly bipectinate seta. Claws on tarsi II to IV with long, coarse tines.

Description

Female

Idiosoma. Length 205 µm, width 115 µm. Dorsal plates uniformly and minutely porose; with few striae of membraneous integument between opposing margins of AD and PD. AD wider than long (Figure 1A), length 67 µm, width 88 µm; anterior margin arched, posterior margin almost truncate. Gland pores in lateral margin. OC triangular, length 15 µm, width 7 µm; with gland pore and pore canaliculus. Length of PD 127 µm, width 90 µm; its length 1.9 times that of AD. PD with two pairs of gland pores, anterior pair somewhat posterior to level with insertion of leg IV. Dorsal setae small, pair of ds-1 slightly posterior to the level of gland pores. Pair of ds-2 in striated integument; ds-3 to ds-5 on PD, arranged as illustrated. Pair of ds-5 level with gland pores. Pair of ds-6 on anal plate.

Length of AE 91 µm, width 103 µm; with three pairs of setae; posterior margin of AE truncate (Figure 1B). PE extending beyond insertion of leg IV. One pair of setae within striated integument between PE. Length of GA 87 µm, width 72 µm; anterior margin truncate, lateral margin diverging from anterior margin to level with posterior edge of PE. GA with three pairs of pgs. Ovipositor long, extending beyond anterior margin of GA and posterior margin of AE.

Gnathosoma. Length 59 µm, width 46 µm, 1.2 times longer than wide. Gnathosoma 0.28 of length of idiosoma. Tectum broadly arched (Figure 1D). Rostrum short, far from reaching end of P-2. P-2 with a dorsal seta. P-3 with spiniform medial process. P-4 with three setae in basal whorl, one spur, one ventral and lateral seta, and a spur-like tip (Figure 1C).

Legs. Leg IV longer than leg I. Lateral flanks of legs I and II delicately punctate. Tibia I with slender base, then widened; its length surpassing that of telofemur I. Tibiae and relevant telofemora of following legs similar in length. Telofemur I 1.8 times longer than high. Leg chaetotaxy (solenidia included, pas excluded): leg I, 0, 2, 3, 5, 7, 7 (Figure 1E); leg II, 0, 2, 3, 4, 5, 4 (Figure 1F); legs III and IV, 1, 2, 2, 3, 5, 3 (Figures 1G and H). Genu II with dorsal alveolus but no seta seen. Tibia I with three slender ventral setae, a ventrolateral seta and three dorsal setae. On tibia II ventromedial seta slightly wider than ventral seta. Ventromedial seta on tibia III long and wide, apical seta of tibia III only slightly widened. Ventromedial seta of tibia IV delicately widened, apical seta slender. Tarsi I to IV each with pair of pas.

Length of claws increasing from tarsus I to III. Claws on tarsus I with accessory process but no pecten. Pectines of claws II to IV with very coarse tines. Central sclerite with small bidentate process.

Remarks

Actacarus festivus has a short PD relative to the length of the AD, there is one pair of setae within the membraneous ventral integument, and the margins of the female GA are convergent instead of almost parallel-sided. The characters are shared with *A. giganteus* Krantz, 1971, a species recorded from the Caribbean (Krantz, 1971). The Caribbean species is somewhat larger, its idiosoma and the dorsal and ventral plates are more slender than in *A. festivus*, the dorsal plates are coarsely punctate in *A. giganteus* but minutely porose in *A. festivus*.

The arrangement of the dorsal plates resembles that of *A. latus* Newell, 1984. Beside the number of setae on the AE (three in *A. festivus*, four in *A. latus*) there are differences in the size (length of female 205 µm in *A. festivus*, 334–355 in *A. latus*), the ornamentation of the dorsal plates (minutely and uniformly porose in *A. festivus*, pitted in *A. latus*), shape of the female GA and the arrangement of the pgs. *Actacarus latus* is recorded from the Eastern Pacific, from off the coast of Chile (Newell, 1984).

The shape of the female GA of *A. australis* Bartsch,

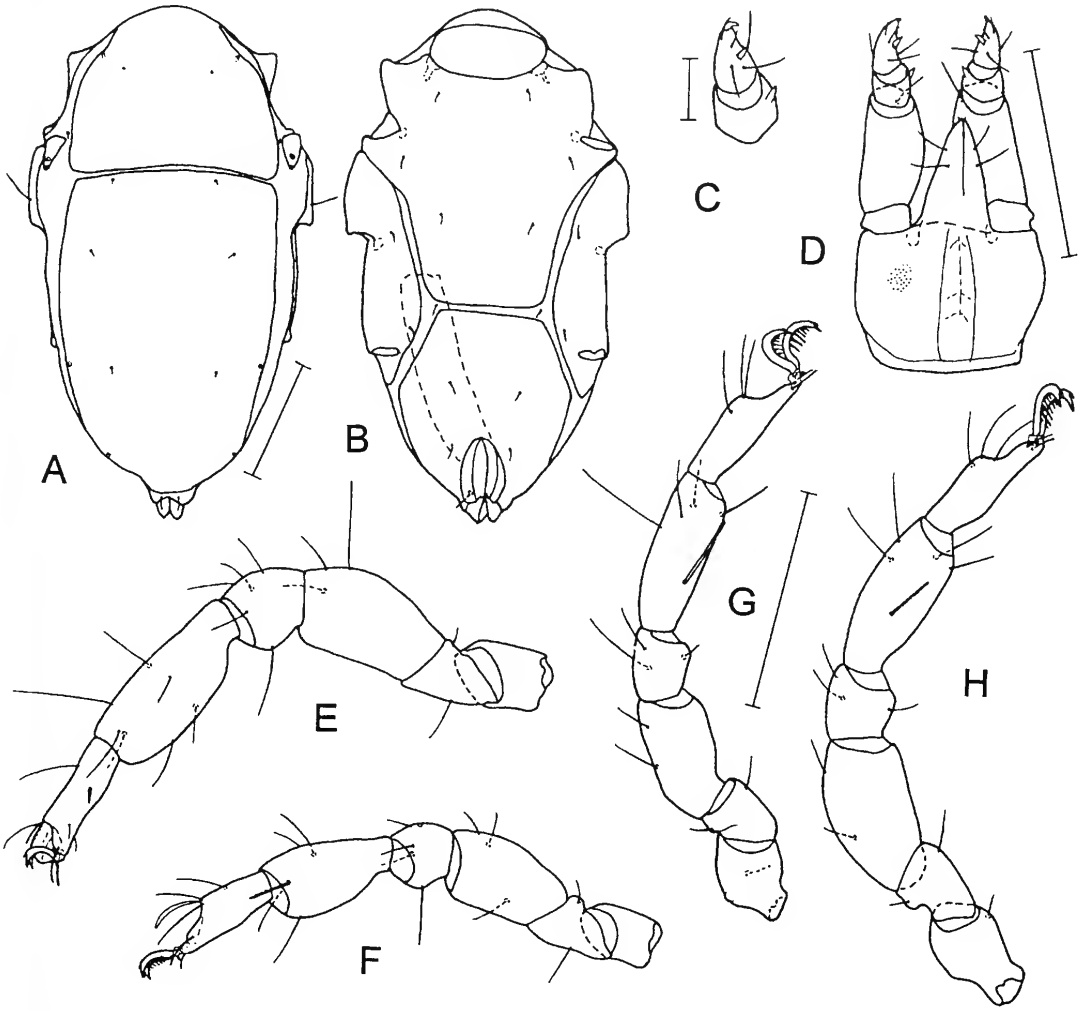


Figure 1 A–H. *Actacarus festivus* sp. nov., female. A, Idiosoma, dorsal; B, idiosoma, ventral; C, P-3 and P-4, ventral; D, gnathosoma, ventral; E, leg I, medial; F, leg II, medial; G, leg III, medial; H, leg IV, medial. Scale = 50 µm (A,B,D–H); scale = 10 µm (C).

1993 is similar to that of *A. festivus*. In contrast to *A. festivus* the PE of *A. australis* bears three ventral setae and the ovipositor is much shorter.

Distribution

Indian Ocean, Western Australia, Dampier. From shallow water deposits.

Actacarus pacificus Bartsch, 1979
Figure 2A–D

Actacarus pacificus Bartsch, 1979: 231–234, figures 1–14; Bartsch, 1993: 75, 76, figure 1; Abé, 1997: 33–34, figure 2A–C.

Actacarus orthotectus Newell, 1984: 245–247, figures 705–707.

Actacarus marindicus Otto, 2000c: 116–119, figures 3a–e, 4a–e (new synonymy).

Material Examined

Australia: Western Australia: 1 female, Dampier, 20°39'S, 116°42'E, sandy beach, coarse, unsorted sand in middle part of tidal slope, 0–3 cm sediment depth, 3 August 2000, coll. I. Bartsch (WAM T52096).

Diagnosis

Idiosomal length 263 µm. Dorsal and ventral plates with delicate punctation. Opposing margins of AD and PD and AE and GA truncate (Figure 2A). PD more than twice the length of AD. OC with triangular anterior portion extending beyond gland pore. Pair of ds-2 within membraneous integument.

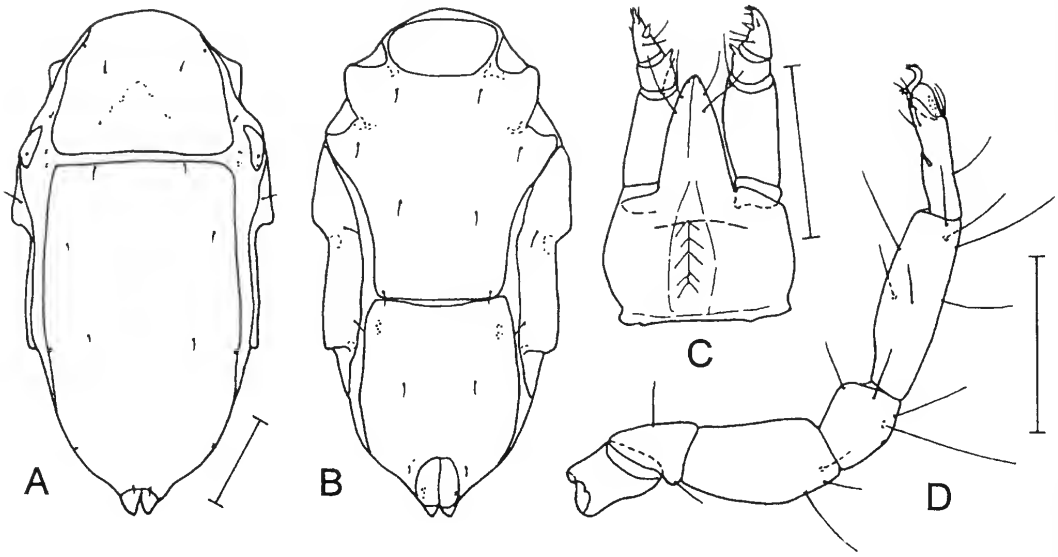


Figure 2 A–D. *Actacarus pacificus* Bartsch, 1979, female. A, Idiosoma, dorsal; B, idiosoma, ventral; C, gnathosoma, ventral; D, leg I, medial. Scale = 50 µm.

AE with four pairs of setae. PE with one dorsal and two ventral setae (Figure 2B). Ovipositor in rest extending beyond anterior margin of GA. Gnathosoma 0.27 of idiosomal length. Rostrum about as long as gnathosomal base. Tectum very slightly arched. Rostrum extending almost to end of P-2 (Figure 2C). Both pairs of maxillary setae in distal half of rostrum. Legs less than 0.7 of idiosomal length. Genua shorter than telofemora and tibiae. Leg chaetotaxy: leg I, 0, 2, 3, 5?, 7, 7; leg II, 0, 2, 3, 4, 5, 4; legs III and IV, 1, 2, 2, 3, 5, 3. Tibia I with three slender ventral setae (Figure 2D); tibiae II to IV with two ventral setae, on tibia III these setae faintly bipectinate. Paired claws on tarsus I with accessory process but no pecten, claws II to IV with few large tines.

Remarks

According to Bartsch (1993) and Abé (1997), *Actacarus pacificus* is found widely spread in the Indo-Pacific region. In contrast, Otto (2000c) expected specimens from Rottnest Island, Western Australia, collected and identified by Bartsch (1993), not to be identical with *A. pacificus*. Otto described the Australian specimens under the name of *Actacarus marindicus* Otto, 2000. The differences between the individuals from the Hawaiian Islands and Australia were said to be (1) a coarser punctation of the PD in the Hawaiian material and (2) presence of a single bipectinate seta on tibia III of the type specimens, instead of two such setae as present in the Australian individuals. In respect to the first mentioned character, the differences stated by Otto (2000c) cannot be confirmed by the present author. The dorsal plates of the holo- and paratype female and male of *A. pacificus* are delicately punctate, as the ventral plates are. Unfortunately, Otto (2000c) did not mention if the illustration (Otto, 2000c: figure 8b) was prepared on the base of the holo- or a paratype, a female or male. In the illustration the position of the setae assumedly representing the ds-4 is unusual (and not corresponding to the situation in either the holotype or the paratypes), and the ds-3 are not illustrated. The second character used by Otto (2000c) to distinguish between *A. pacificus* and *A. marindicus* was the shape of a seta on tibia III. The basal one of the two ventral setae on tibia III is longer than the distal one and delicately bipectinate. The distal seta has fuzzy margins and such a tip (Otto, 2000c: 118) due to a very subtle bipectination. These fuzzy margins are not recognizable when viewing the edge of that seta. Presence or absence of fuzzy margins is inadequate for discriminating between species as their perceptibility is influenced by the preservation, storing, clearing and mounting medium.

Bartsch (1993: 76) mentioned the shape of the basal seta on tibia I as a possible diagnostic character to distinguish between the Hawaiian and Western Australian specimens. A re-examination of the holo- and paratypes showed that the relevant seta is somewhat more stout than the other ventral setae but not distinctly pectinate.

Otto (2000c) also discussed the state of *A. orthotectus* Newell, 1984. That species was described from the Juan Fernandez Islands, Chile (Newell, 1984). Bartsch (1993) and Abé (1997) believed it to

be synonymous with *A. pacificus*. Otto (2000c) re-established the Chilean species (*A. orthotectus*) because of its slender P-2 and presented an illustration of the palps of both a Chilean and Western Australian specimen (Otto, 2000c: figure 3e and f). The palps are said to show a lateral aspect. In general, the P-2 of *Actacarus* species are slightly flattened but narrow in dorsal aspect. It is likely that one of the illustrations (Otto, 2000c: figure 3f) represents a dorsolateral aspect of the palps, a notion corroborated by the insertion of the dorsal seta in that figure. In lateral aspect the shape of the palps may be the same in specimens from both the southeastern and northern Pacific.

Nonetheless, several cryptic species may exist in the Indo-Pacific region, each restricted to a small-scale geographical area, and the specimens from Rottnest Island (*A. marindicus*) may prove to be distinct. The presently described morphological characters allow no separation between individuals from the Hawaiian Islands and Western Australia.

The *Actacarus* species recorded from Australia are *A. australis*, *A. chelonis* Otto, 2000, *A. cornutus* Otto, 2000, *A. nanus* Otto, 2000, *A. pacificus*, *A. spinosus* Otto, 2000, and the above described *A. festivus*. The AE of each of *A. pacificus*, *A. nanus* and *A. spinosus* bears four pairs of setae, the PE two ventral setae. *A. spinosus*, the smallest species, has an idiosomal length of 186–194 µm, its P-4 has a conspicuously bent seta (instead of a spur), on tibia I is one of the ventral setae coarsely bipectinate, one faintly pectinate, tibiae III and IV both bear one long bipectinate and one very short and slender ventral seta. *Actacarus nanus* has an idiosomal length of 198–212 µm, the ds-2 are close to the level of the posterior margin of the AD and the OC are rather short, the female GA is short, the distance from the anterior margin of the GO to the GA almost equals half the length of the AE, and none of the ventral setae on tibia I is bipectinate. *Actacarus pacificus* has an idiosomal length of 235–282 µm (Australian specimens), the length of the GA relative to that of the AE is less than in *A. nanus*, the ventral setae on tibia I are apparently smooth.

Distribution

Southeastern Pacific (Chile, Robinson Crusoe Island), Northeastern Pacific (Hawaiian Islands), Sea of Japan (Hokkaido), Eastern Indian Ocean (Western Australia, Rottnest Island, Dampier). Intertidal to 10 m.

Subfamily Anomalohalacarinae Bartsch, 1985

Genus *Anomalohalacarus* Newell, 1949

Anomalohalacarus dampierensis sp. nov.

Figures 3A–H, 4A–G

Material Examined

Holotype

Male, Dampier, 20°39'S, 116°42'E, Western Australia, Australia; sandy beach, coarse, unsorted sand in middle part of tidal slope, 0–3 cm sediment depth, 3 August 2000, coll. I. Bartsch (WAM T52097).

Paratype

Australia: Western Australia: 1 protonymph, same data as for holotype (WAM T52098).

Etymology

An adjective referring to the type locality Dampier.

Diagnosis

Idiosomal length 300 µm. AD and PD almost equal in length. PD undivided. Setae ds-5 lacking. Setae on epimera IV lacking. Anterior margin of male GA arched. GA with at least four pairs of pgs. P-2 with two setae. Tibia I with two short, bipectinate ventral spurs. Tibia I with eight setae, two of them spur-like. Tibiae II, III and IV each with pair of ventral setae which are slightly pectinate on tibiae III and IV but pectinate and slender on tibia II. One of the two setae on telofemur IV conspicuously stout.

Description

Male

Idiosoma. Length 300 µm; very slender, much longer than wide. Dorsal and ventral plates delicate. Membraneous integument faintly striated. Length of AD 57 µm, width 39 µm; with pair of gland pores in lateral margin and pair of ds-1 posterior to gland pores (Figure 3A). PD undivided, its length 57 µm, width 30 µm; with pair of pores in posterior third of plate and small ds-6 in posterior margin. AD and PD each with pair of gland pores. Setae ds-1 to ds-4 long, slender; ds-1 inserted on AD, ds-2 and ds-3 within striated integument; ds-5 not seen; ds-6 very short, in posterior margin of PD.

AE divided by striated integument into right and left half (Figure 3B). Length of AE 42 µm (to camerostome). Each half with three setae and an epimeral pore. Long apodemes between epimera I and II. PE in posterior fourth of idiosoma. Each plate with one dorsal and two ventral setae; no seta in area representing epimeral plate IV. Anterior margin of GA broadly arched, with at least four pairs of perigenital setae (genital region obscured by legs III and IV and hence setae difficult to discern). Spermatopositor extending far beyond GA. Position of sgs not discernable in the single male available.

Gnathosoma. Very slender (Figure 3C), its length

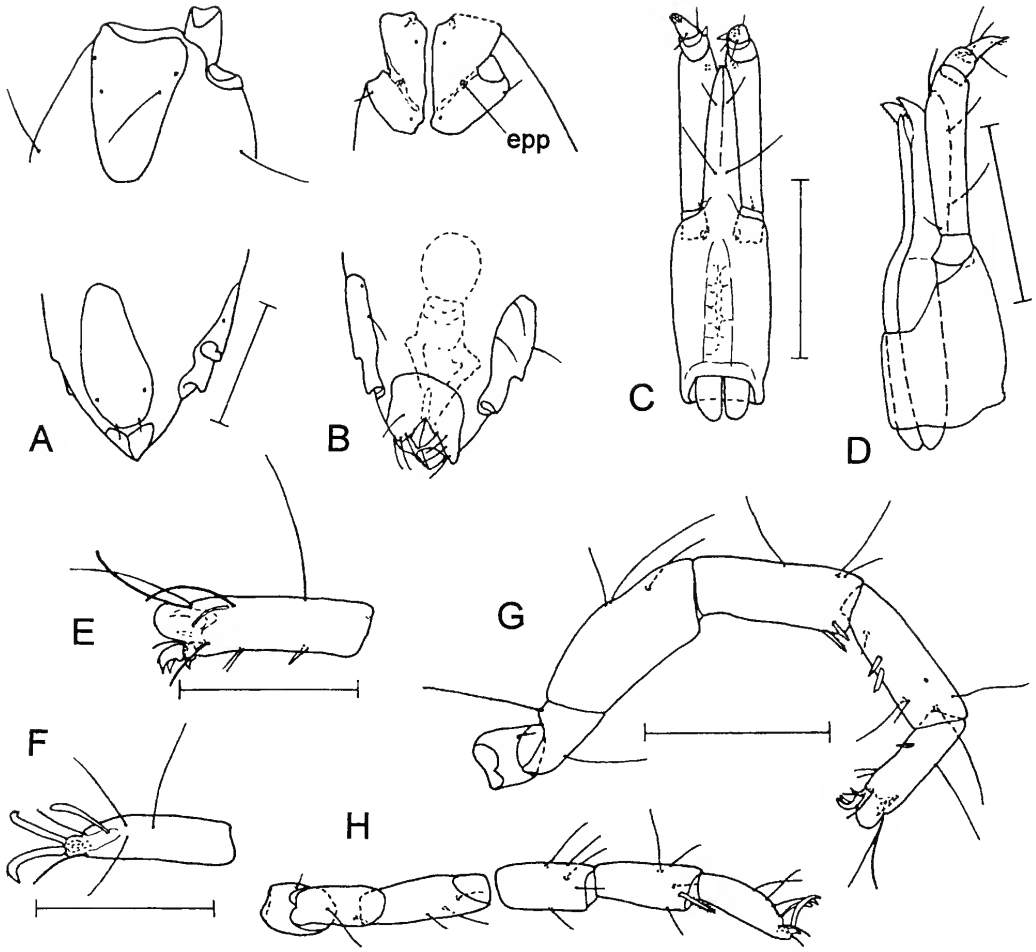


Figure 3 A–H, *Anomalohalacarus dampierensis* sp. nov., male. A, Anterior and posterior part of idiosoma, dorsal; B, AE, PE and GA, ventral; C, gnathosoma, ventral; D, gnathosoma, lateral; E, tarsus I, lateral; F, tarsus II, dorsal; G, leg I, medial; H, leg II, ventral and ventromedial. Scale = 50 µm (epp, epimeral pore).

87 µm, width 28 µm. Rostrum almost as long as gnathosomal base; with two pairs of long maxillary setae; apex with two pairs of minute rostral setae. P-2 with short, slender basal and stout distal seta (Figure 3D). P-3 with large medial spine. P-4 with three setae in basal whorl; apex with minute ventral and lateral seta and flattened dorsal seta.

Legs. Leg I longer and wider than the other legs. Genu and tibia I almost equal in length and shorter than telofemur I. Both lateral and medial fossa membrane of tarsus I large. Tarsi II to IV lack prominent membranes. Leg chaetotaxy (solenidia and pas included, famulus excluded): leg I, 1, 2, 3, 5, 8, 9; leg II, 1, 2–3, 3, 5, 5, 6; leg III, 1, 1, 2, 3, 5, 5; leg IV, 0, 0, 2, 3, 5, 5. Dorsal seta of basifemur I conspicuously long and stout (Figure 3G). Genu I with two short, slightly bipectinate spurs, inserted adjacent and ventromedially. Tibia I with two ventral spurs; most of dorsal setae slender except rather thick distolateral seta. Tarsus I with three ventral setae, one spur-like, two short and slender. Dorsal and dorsomedial fossary seta slender, dorsolateral fossary seta and dorsolateral solenidion conspicuously thick (Figure 3E). Famulus slender, pressed to lateral fossa membrane; its length 8 µm. Genua II to IV with slender ventral setae. Tibiae II to IV each with pair of ventral setae; on tibia II one of these setae pectinate and one slender (Figure 3H), on tibiae III and IV both setae equal-sized, with very delicate pectination. Tarsus II with large, claviform solenidion in dorsolateral position (Figure 3F); the three dorsal setae slender. Tarsi I to IV with pair of pas singlets. Telofemora III and IV each with two dorsal setae, on telofemur IV one of these setae stout.

Paired claws of tarsus I short, with basiventral

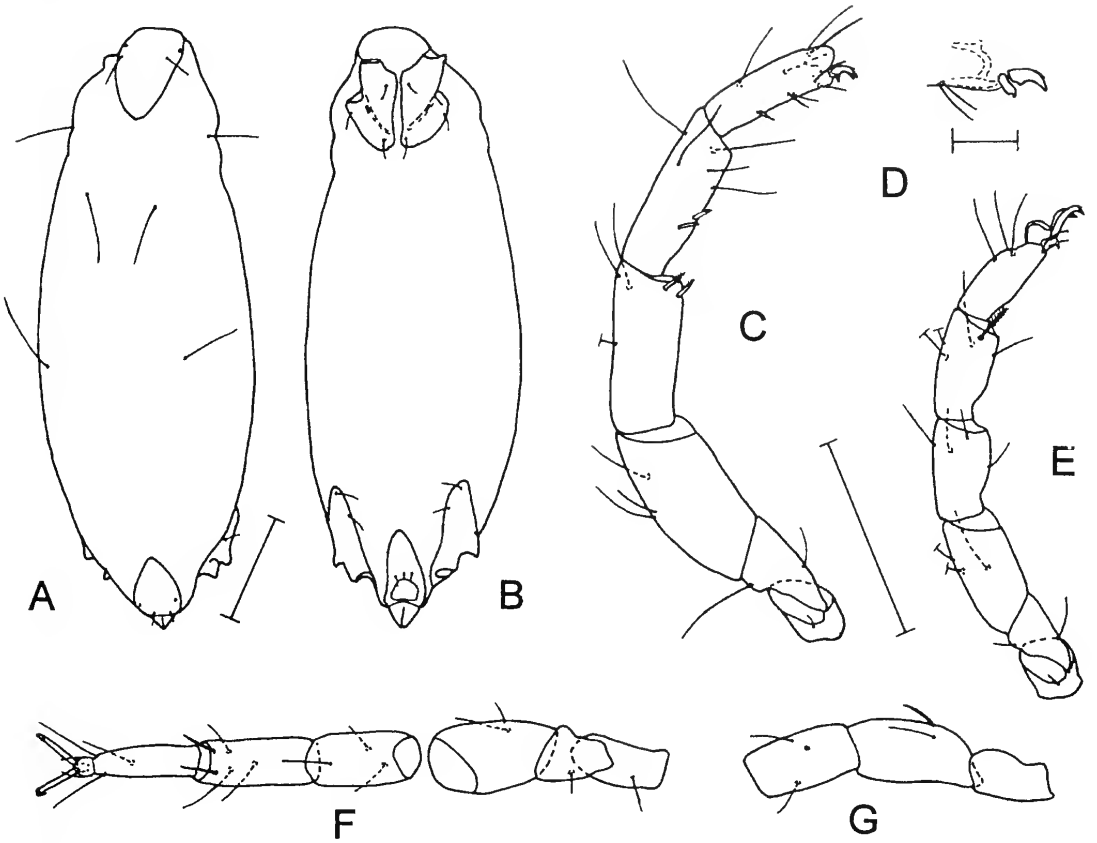


Figure 4 A–G, *Anomalohalacarus dampierensis* sp. nov., protonymph. A, Idiosoma, dorsal; B, idiosoma, ventral; C, leg I, medial; D, tip of tarsus I with claw; E, leg II, medial; F, leg III, ventral; G, trochanter, femur, genu IV. Scale = 50 µm (A–C, E–G), scale = 10 µm (D).

process (as in protonymph, Figure 4D). Paired claws of tarsi II to IV with accessory process but without pecten. Central sclerite with minute claw-like process.

Protonymph

Idiosomal length 268 µm, width 100 µm. Arrangement of plates and setae as illustrated (Figure 4A and B). AE as in male with three pairs of setae, PE with one dorsal and two ventral setae. Gnathosoma slender, length 80 µm, width 25 µm, number and arrangement of setae same as in adults. Leg chaetotaxy (with solenidia and pas): leg I, 1, 2, 3, 5, 7, 9 (Figure 4C); leg II, 1, 2, 3, 4, 5, 6 (Figure 4E); leg III, 1, 1, 2, 3, 5, 5 (Figure 4F); leg IV, 0, 0+2 (basi- + telofemur), 3, 5, 5. Genu I with two spur-like, pectinate setae. Tibia I with two spur-like setae. Tibiae II with one slender and one pectinate seta; tibiae III and IV each with two faintly bipectinate setae. One of dorsal setae on telofemur IV stout (Figure 4G).

Remarks

Most species of the genus *Anomalohalacarus* are known from the North Atlantic and the Mediterranean. There is a single species from the western Pacific, from Japan, and three from the Indian Ocean, two from Western Australia and one species of unknown identity from the Bay of Bengal (Abé, 1996; Bartsch, 1976a, b, 1981b, 1985a, 1991a, 1993; Monniot, 1967; Morselli and Mari, 1981, 1982, 1989; Rao, 1970).

The idiosoma and dorsal and ventral plates are similarly shaped in the males of the two Australian species, *A. macellus* Bartsch, 1993, from Rottnest Island, and A. *dampierensis*. The two species differ in the setation of the legs. Tibia I of *A. dampierensis* bears eight setae, two of them are spur-like, in contrast, tibia I of *A. macellus* has 10 setae. The protonymph of *A. dampierensis* has a longer genital plate than that nymph of *A. macellus*.

Anomalohalacarus biformis Abé, 1996, from Hokkaido, Japan (Abé, 1996), has 10 setae on tibia I.

The species is easily separated from the two Australian ones by the three ventral bristle-like setae on tibiae II and III.

Fourteen species have been described from the North Atlantic and adjacent basins. Two species, *Anomalohalacarus anomalus* (Trouessart, 1894) and *A. litoralis* Bartsch, 1981, differ from the others in that the idiosomal integument is very prominently striated (cf. Monniot, 1967: figure 1C), the P-2 bears two large setae, one in the basal, one in the distal portion, and tibia I three ventral setae (two spur-like, one seta-like) in the basal half of the segment. In the other North Atlantic species, the striae of the integument are rather delicate, the P-2 bears a single seta which is slender and inserted near the base of that segment, and in the basal portion of tibia I there are one or two setae which are either setiform or seti- and spiniform. Except for *A. marcandrei* Monniot, 1967, the PD of adult North Atlantic species is divided into a right and left half.

The three species from the Indo-Pacific region differ from those of the North Atlantic and its adjacent basins by (1) absence of the ds-5 and (2) absence of the posterior pair of setae on the PE (generally attributed to epimeron IV). The PD is undivided, the idiosomal integument delicately striated, P-2 bears two setae, the basal seta is short and slender, similar to that of the majority of the North Atlantic species, the posterior seta is stout, resembling that seta of *A. anomalus* and *A. litoralis*. In the basal portion of tibia I there are more than two ventral setae.

Distribution

Indian Ocean (Western Australia, Dampier). Intertidal.

Subfamily Halacarinae Viets, 1927

Genus *Arhodeoporus* Newell, 1947

Arhodeoporus corallicolus Otto, 2000

Figures 5A–F, 6A–F

Arhodeoporus corallicolus Otto, 2000g: 5–7, figure 4.

Material Examined

Australia: Western Australia: 1 female, 1 male, Dampier Archipelago, Enderby Island, West of Rocky Head, 20°32.1'S, 116°26.7'E, sponge garden, 2–13 m, unsorted sandy deposits, 3 August 2000, coll. C. Bryce (WAM T52099 and T52100).

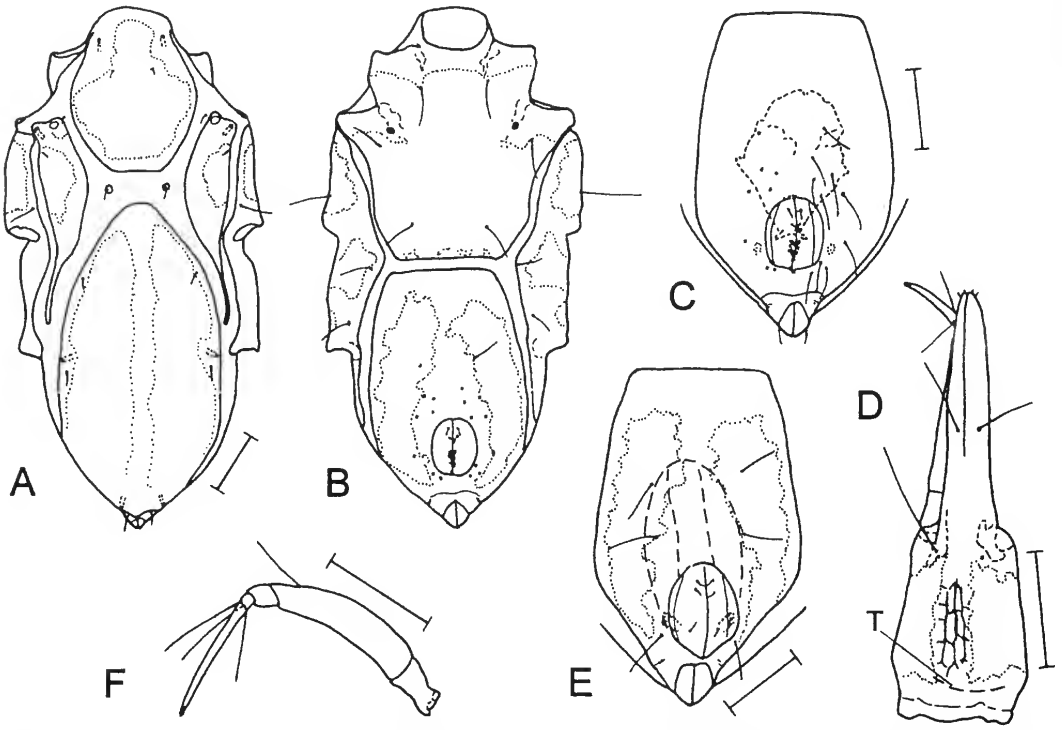


Figure 5 A–E. *Arhodeoporus corallicolus* Otto, 2000. A, Idiosoma, dorsal, male; B, idiosoma, ventral, male; C, genitoanal plate, male; D, gnathosoma, ventral, male; E, genitoanal plate, female; F, palp, lateral, male. Scale = 50 µm (T, tectum).

Diagnosis

Idiosomal length 400–411 µm. Surface of plates smooth but integument pierced by numerous canaliculi. Outline of such porose areolae as illustrated (Figure 5A and B). OC with long tail and one small cornea and, beneath, small spots of eye pigment. Anterior margin of PD ovate. Each of the four pairs of gland pores with a small tube. Pair of ds-2 within striated integument; ds-3 on small platelets; ds-5 just posterior to gland pore. Punctation of AE coarser than that of dorsal plates and GA. Opposing margins of AE and GA truncate. AE with pair of epimeral pores. PE with one dorsal and three ventral setae. Female GA with three pairs of pgs; genital sclerites with three pairs of sgs; two pairs of internal genital acetabula. Ovipositor extending slightly beyond the level of anterior pair of pgs (Figure 5E). Male GA with 17 pgs; genital sclerites with five pairs of sgs and a slightly projecting posterior cone (Figure 5C). Spermatopositor extending well beyond anteriormost pair of pgs. Gnathosoma slender, almost three times longer than wide and 0.44 of idiosomal length. Rostrum distinctly longer than gnathosomal base (Figure 5D). The latter with marginal porose areolae. Rostral trough long; truncate tectum in basal portion of gnathosomal base (Figure 5D). Palps slender (Figure 5F). Basi- and telofemora II to IV flattened; telofemora II to IV about twice as long as high; basifemora dorsally slightly projecting. Tibiae slender, cylindrical. Height of telofemora II to IV 1.8–2.0 times that of relevant tibiae. Tibia I longer than telofemur I, tibiae of following legs as long as or shorter than telofemora. Leg chaetotaxy (solenidia included, pas excluded): leg I, 1, 2, 3, 4, 8, 7 (Figure 6A); leg

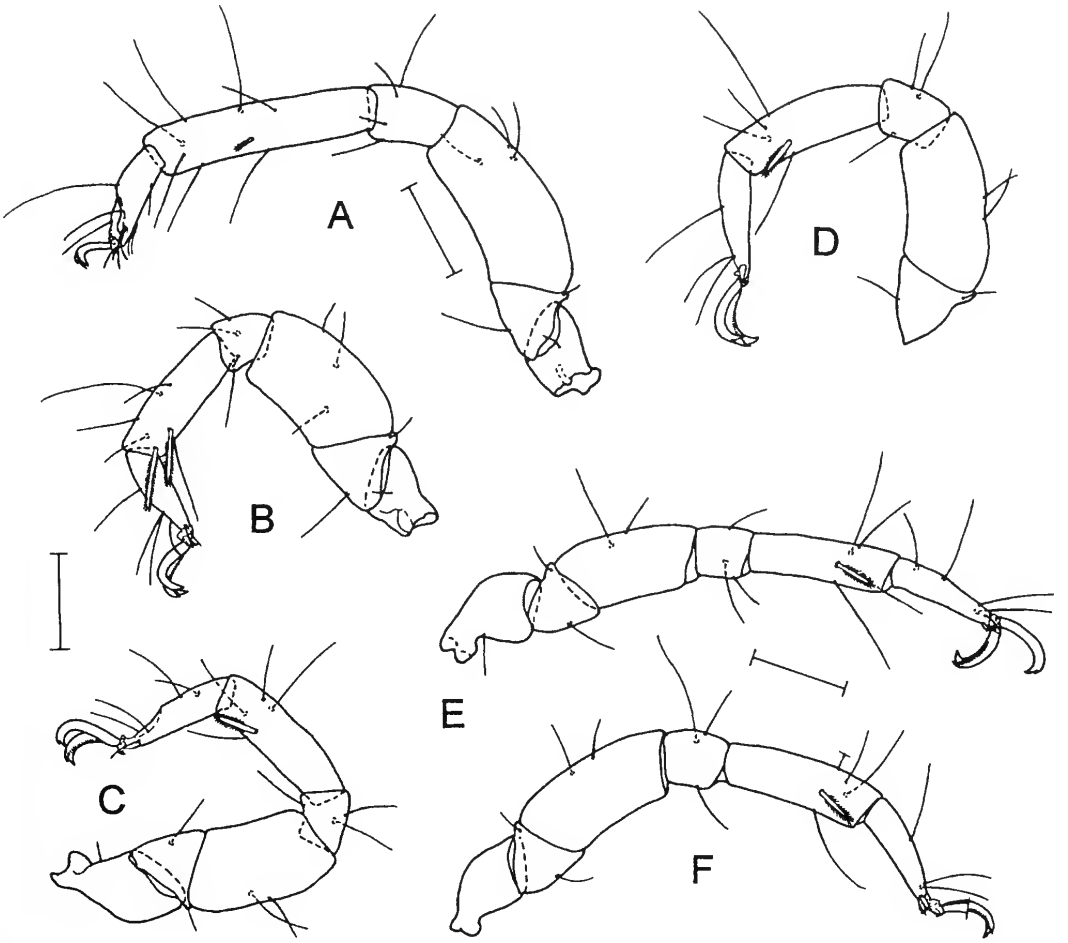


Figure 6 A–F. *Arhodeoporus corallicolus* Otto, 2000, male. A, Leg I, medial; B, leg II, medial; C, leg III, medial; D, basifemur to tarsus IV, medial; E, leg III, medial; F, leg IV, medial. A–D, male from Dampier; E and F, paratype from Great Barrier Reef. Scale = 50 µm.

II, 1, 2, 3, 4, 7, 4 (Figure 6B); leg III, 1, 2, 2, 3, 5, 4 (Figure 6C); leg IV, 0, 2, 2, 3, 5, 3 (Figure 6D). Ventral flank of tibia I with one short, pectinate and three long, smooth setae. Tibiae II to IV with 2, 1, 1 bipectinate and 1, 1, 1 smooth and slender seta. Tarsus I short, less than half length of tibia I. Tarsi I and II with slender pas; tarsus III with slender medial and short, wide lateral pas; tarsus IV with pair of short and wide pas. Claws with accessory process and pecten; tines of pectines very short (seen only at high magnification and oil immersion).

Remarks

The specimens from the Dampier Archipelago have conspicuously flattened telofemora II to IV, their height is almost twice that of the tibiae. The height of the telofemora of the Great Barrier Reef specimens (Otto 2000g: figure 4f and present paper: Figure 6E and F) is less striking, 1.5–1.7. The fixative and the contraction of the muscles may influence the shape of the telofemora. The slight difference in the shape of the PD is expected to be within the variability of this character; the anterior portion of the holotype PD is broadly rounded (Otto 2000g: figure 4a), that of the specimen from Dampier more slender (Figure 5A).

Species most similar to *Arhodeoporus corallicolus* are *A. caudatus* Otto, 2000, *A. clypeatus* Otto, 2000, *A. lizardensis* Otto, 2000, and *A. psammophilus* Bartsch, 1993, all from Australia, from the Great Barrier Reef, the Queensland Plateau and from Rottnest Island, off Perth (Otto, 2000g; Bartsch, 1993). Further species are *A. mactanus* Bartsch, 1991, from the Philippine Island Mactan, and *A. longirostris* Bartsch, 1981, from off the Isles Glorieuses, Mozambique Channel (Bartsch, 1981a, 1982, 1991b). *Arhodeoporus corallicolus* can be identified on the base of the combination of: OC with one cornea; AE and GA separated; punctation of AE coarser than that of the other plates; tibia I with short, delicately pectinate seta; basi- and telofemora flattened. An unique character is that the female genital sclerites bear three pairs of sgs, in contrast to two pairs of setae which is the most common state of this character.

Arhodeoporus corallicolus has very flattened telofemora. In general, the telofemora of halacarid mites are almost cylindrical, but in many species the legs bear large ventral lamellae, e.g. in species of the *Copidognathus gibbus* group (Bartsch, 1994b; Otto, 2000f). In *A. corallicolus* there are no such lamellae.

Distribution

Great Barrier Reef, northeastern Australia, and Dampier, northwestern Australia. Inhabitant of shallow water sandy deposits.

Subfamily Copidognathinae Bartsch, 1983

Genus *Copidognathus* Trouessart, 1888

Copidognathus meridianus Bartsch, 2003

Copidognathus meridianus Bartsch, 2003b: xx–xx, figures 1A–H, 2A–H, 3A–F.

Material Examined

Australia: Western Australia: 3 females, 1 male, Dampier, 20°39'S, 116°42'E, unsorted sand in mid- and upper tidal shore, 31 July 2000 and 1 August 2000, coll. I. Bartsch (WAM T45195–T45198); 1 female, north of Cape Preston, 40 Mile Beach, coarse unsorted sediment, upper tidal shore, 6 August 2000, coll. I. Bartsch (WAM T45199).

Diagnosis

Idiosomal length 360–385 µm. Dorsal plates almost uniformly ornamented with small pits arranged within polygons. AD with three delicately raised areolae. PD without prominent costae. OC with minute cornea. PD with pairs of pores at the level and posterior to ds-5; each pore with large internal gland. Female GA with four pairs of pgs; male GA with 15–16 widely scattered pairs of pgs. Length of gnathosoma almost one third of that of idiosoma. Length:width ratio of gnathosoma 1:0.7; rostrum triangular, about as long as gnathosomal base and extending just beyond P-2. Tectum truncate. Leg chaetotaxy (solenidia and pas included): leg I, 1, 2, 5, 4, 7, 11; leg II, 1, 2, 5, 4, 7, 8; leg III, 1, 2, 2, 3, 5, 5; leg IV, 0, 2, 2, 4, 5, 5. Tibiae II to IV with 2, 1, 1 bipectinate setae. Tarsi I to IV with 4, 4, 3, 3 dorsal setae (solenidia included). Pectines of claws II to IV with delicate tines.

Remarks

This rather large-sized psammophilous *Copidognathus* species can be separated from congeners by the unique combination of (1) dorsal plates almost uniformly ornamented and (2) genu IV with four setae.

Distribution

Tropical Western Australia, Dampier. Present in sandy deposits, in mixed coarse and fine sand. In the Dampier area, this species dominated the intertidal psammophilous halacarid fauna.

Subfamily Lohmannellinae Viets, 1927

Genus *Scaptognathides* Monniot, 1972

Scaptognathides hawaiiensis Bartsch, 1988

Figure 7A–E

Scaptognathides hawaiiensis Bartsch, 1988: 221, 222, figures 27–30; Bartsch, 1991c: 59, figure 1A–H.

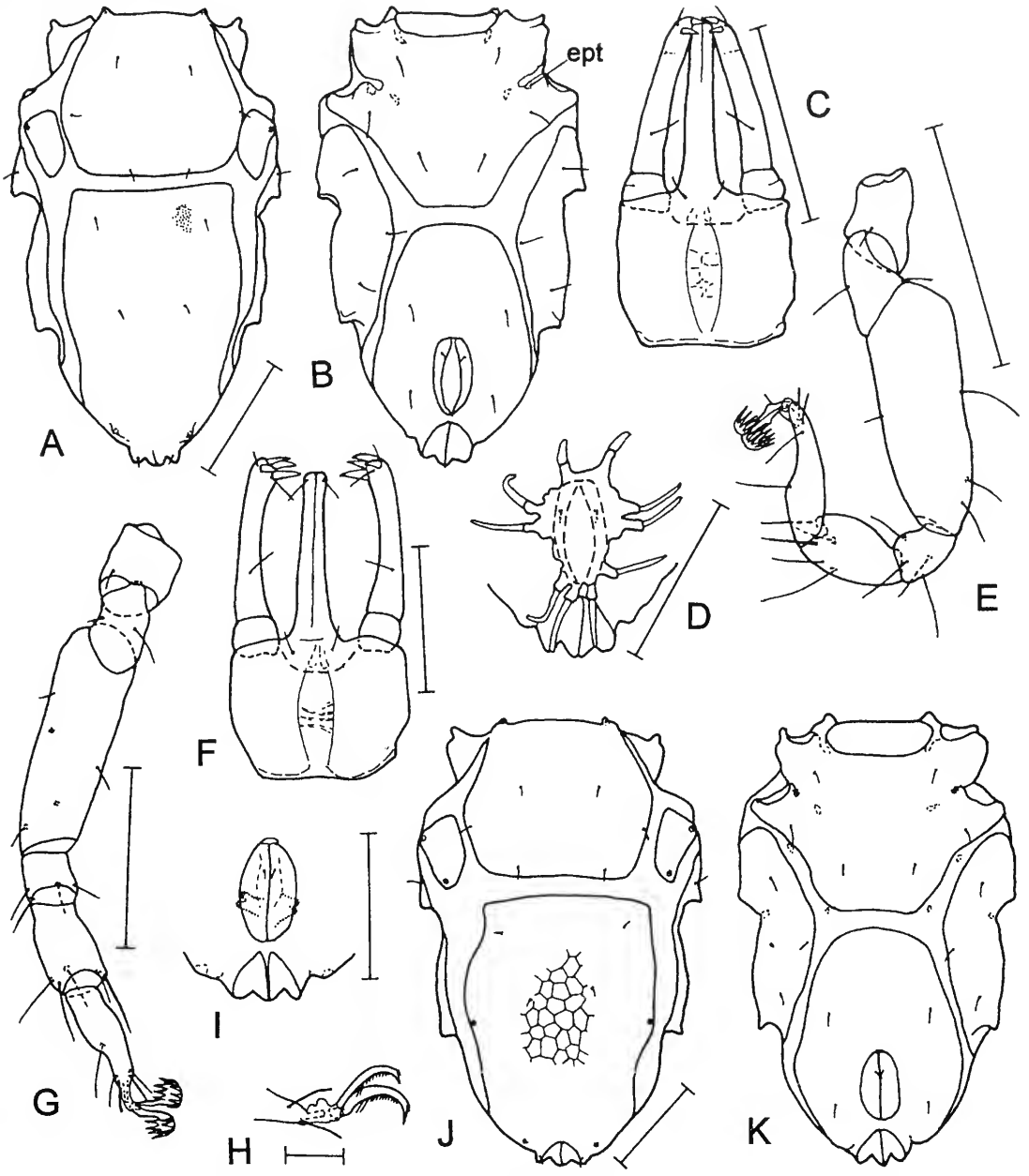


Figure 7 A–D. *Scaptognathides hawaiiensis* Bartsch, 1988, female. A, Idiosoma, dorsal; B, idiosoma, ventral; C, gnathosoma, ventral; D, ovipositor; E, leg I, medial. (ept, epimeral tube). F–K. *Scaptognathides ornatus* Bartsch, 1988, female. F, gnathosoma, ventral; G, leg I, ventral; H, tip of tarsus II, medial; I, genital opening; J, idiosoma, dorsal; K, idiosoma, ventral. Scale = 50 µm (A–G, I–K), scale = 10 µm (H).

Material Examined

Australia: Western Australia: 3 females, Dampier, sandy beach, coarse, unsorted sand, lower part of tidal slope, 2–15 cm sediment depth, 4 August 2000, coll. I. Bartsch (WAM T52101 and T52102).

Diagnosis

Idiosomal length 170–180 µm. Dorsal and ventral plates minutely pitted. AD, OC and PD each with one pair of gland pores (Figure 7A). Pairs of ds-1, ds-2 and ds-3 on AD, ds-4 and ds-5 on PD, adanal setae on anal valves. AE with three pairs of setae

and pair of small epimeral tubes (Figure 7B). GA with two pairs of pgs, genital sclerites with one pair of sgs. Gnathosomal length 0.44–0.47 times of that of idiosoma. Margin of tectum truncate. Rostrum slightly longer than gnathosomal base (Figure 7C). Two of the four apical palpal spines pectinate. Leg I somewhat longer and considerably more stout than following legs. Length of legs I and IV about 0.75 of that of idiosoma. Leg chaetotaxy (very short solenidia excluded, pas included): legs I and II, 1, 2, 4, 4, 5, 5; legs III and IV, 1, 2, 2, 3, 5, 5. Length:height ratio of telofemora II to IV about 2.2–2.3. Paired claws of tarsus I with large, umbrella-like arranged tines (Figure 7E). Pectines of claws of tarsi II to IV seen only at higher magnification; basalmost tine twice the length of the other very delicate tines.

Supplementary notes

Ovipositor with 10 pairs of delicately sclerotized, lamellar genital spines (Figure 7D).

Remarks

The PD of *Scaptognathides hawaiiensis* bears a single pair of gland pores situated near the posterior margin of the plate. In the other Australian species, the PD has two pairs of gland pores, one pair about the level of insertion of leg IV, the other pair near the posterior margin, similar to *S. hawaiiensis*.

Records of *S. hawaiiensis* are from the Hawaiian Archipelago, Hong Kong and northwestern Australia. There are small differences in the shape of the female GA, with the anterior margin oviform in the individuals from the Hawaiian Archipelago (Bartsch 1988: figure 28) but almost truncate in those from the Dampier area. Considering the delicateness of the plates, which easily can be deformed, the differences mentioned are thought to be negligible.

Distribution

Northeastern Pacific (Hawaiian Islands), South China Sea (Hong Kong), Eastern Indian Ocean (Western Australia, Dampier). Intertidal sandy deposits.

Scaptognathides ornatus Bartsch, 1988
Figure 7F–K

Scaptognathides ornatus Bartsch, 1988: 222–224, figures 31–39.

Material Examined

Australia: Western Australia: 1 female, Dampier, 20°39'S, 116°42'E, sandy beach, coarse, unsorted sand in lower part of tidal slope, 2–15 cm sediment depth, 4 August 2000, coll. I. Bartsch (WAM T52103).

Diagnosis

Idiosomal length 217 µm. Dorsal plates reticulated (Figure 7J). AD with one pair of pores, OC and PD each with two pairs of gland pores. Pair of ds-1, ds-2 and ds-3 on AD, ds-4 near anterolateral corners of PD, ds-5 situated in middle of plate anterior to the level of pair of glp-4. Marginal areas of ventral plates faintly reticulated, ventral portions punctate. GA with two pairs of pgs (Figure 7K) and two pairs of internal genital acetabula (Figure 7I), its genital sclerites with one pair of sgs. Length of gnathosoma 0.48 times that of idiosoma. Tectum concave, median margin truncate. Rostrum somewhat longer than gnathosomal base (Figure 7F). Two of apical palpal spines pectinate. Legs I and IV almost 0.75 of idiosomal length. Length of genu I about 0.6 and 0.2 times that of tibia and telofemur I, respectively. Telofemora II to IV slender, almost three times longer than high. Leg chaetotaxy (very short solenidia excluded): legs I and II, 1, 2, 5, 4, 5, 5; legs III and IV, 1, 2, 2, 3, 5, 5. Paired claws of tarsus I with long, umbrella-like arranged tines (Figure 7G); claws of tarsi II to IV with minute accessory process, pecten with tines, two basalmost tines enlarged (Figure 7H).

Remarks

The two species, *Scaptognathides ornatus* and *S. hawaiiensis*, present in Dampier in the same beach, are easily separated even at low magnification; *S. ornatus* is larger, has reticulate dorsal plates and slender telofemora II to IV.

From Australian shores, six species of *Scaptognathides* are recorded, *S. australis* Bartsch, 1993, *S. hawaiiensis*, *S. heraldensis* Otto, 2000, *S. ornatus*, *S. tomkinsae* Otto, 2000, and *S. undulatus* Otto, 2000. Characters to identify adults (and assumedly nymphs as well are):

Scaptognathides australis: OC slender, at least four times longer than wide, and with a single gland pore; PD with two pairs of gland pores.

Scaptognathides hawaiiensis: the only species with a single pair of gland pores on OC and PD.

Scaptognathides heraldensis: OC with one gland pore, PD with two pairs of pores; in contrast to *S. australis*, the OC are rhomboid, about twice as long as wide.

Scaptognathides ornatus: both OC and PD with two pairs of gland pores. Telofemora II to IV slender; tarsus III with three dorsal setae.

Scaptognathides tomkinsae: PD with two pairs of gland pores; OC with a single pore, its posterior edge with a minute seta instead of a gland pore.

Scaptognathides undulatus: both OC and PD with two pairs of gland pores; tarsus III with four dorsal setae, instead of three as present in the other species.

Distribution

Northeastern Pacific (Hawaiian Islands), Eastern Indian Ocean (Western Australia, Dampier). Intertidal.

Genus *Scaptognathus* Trouessart, 1889

Scaptognathus exquisitus Otto, 2000

Figure 8A–E

Scaptognathus exquisitus Otto, 2000b: 539–543, figure 4.

Material Examined

Australia: Western Australia: 1 female, Enderby Island, West of Rocky Head, 20°32.1'S, 116°26.7'E, sponge garden, 2–13 m, unsorted sandy deposits, 3 August 2000, coll. C. Bryce (WAM T52104).

Diagnosis

Idiosomal length 210 µm. Dorsal and ventral plates pitted, AD with the pits arranged within polygons (Figure 8A). AD very wide, posterior margin arched. OC small, rounded. Anterior margin of PD truncate. AE wider than long, with large epimeral pores and circular markings. PE with funnel-like structures anterior to insertion of legs III and IV (Figure 8A and D). Female GA bipartite; posterior portion with two pairs of pgs (Figure 8B); genital sclerites with single pair of sgs. Gnathosoma almost twice as long as wide; its length 0.79 of that of idiosoma. Spatula-shaped rostrum shorter than gnathosomal base (Figure 8C). Legs slender; leg I 0.7 of idiosomal length. Lateral flanks of basi- and telofemora with small, deep foveae. Leg chaetotaxy (solenidia, famuli and pas excluded; bipectinate setae in roman numerals): leg I, 1, 1, 4+II, 3+II, 4+V, 4+I (Figure 8E); leg II, 1, 1, 5, 3+I, 3+II, 3+I; leg III, 1, 1, 2, 3, 3+III, 3; leg IV, 1, 1, 2, 3, 3+III, 3. Tarsus I with 'hollow' claviform solenidion and solid, digitiform famulus. On either side of tarsi I and II one setiform and one distinctly shorter pas. Tarsus III with pair of setiform pas, medial pas with adjacent short seta. Tarsus IV with pair of small, setiform pas. Claws with small accessory process, else smooth. Central sclerite without dent-like process.

Supplementary notes

PE with funnels anterior to insertion of legs III and IV (Figure 8D).

Remarks

The individual in Otto (2000b: figure 4A, B) shows much wider areas between the dorsal and ventral plates than are present in the specimen from the

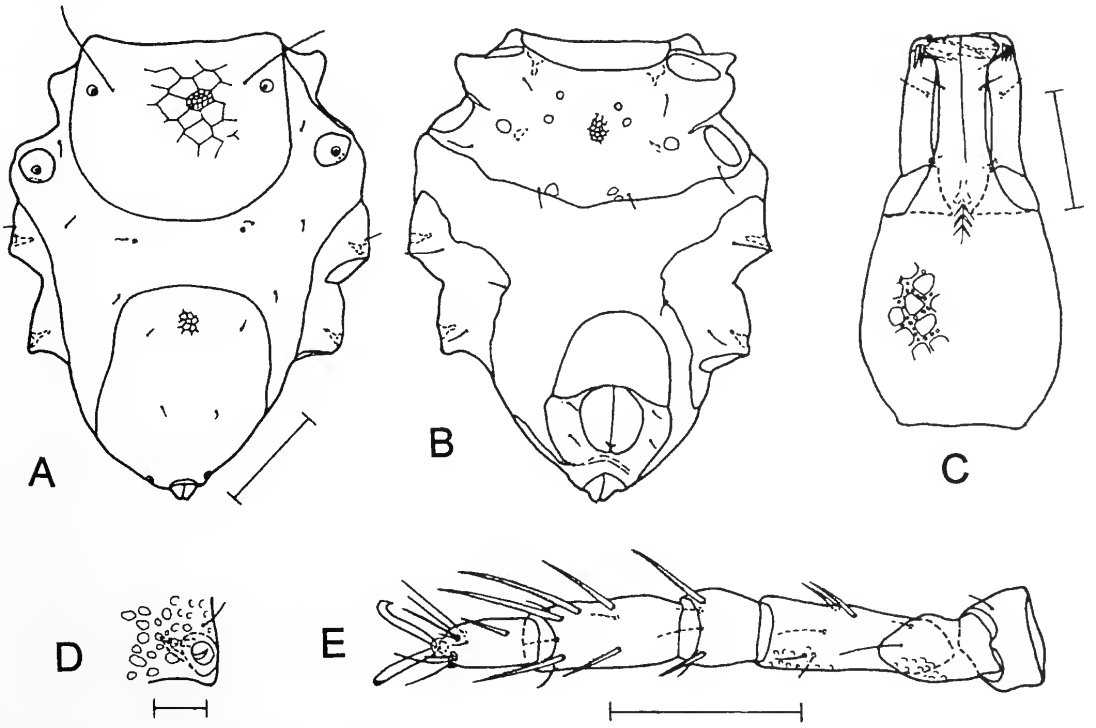


Figure 8 A–E. *Scaptognathus exquisitus* Otto, 2000, female. A, Idiosoma, dorsal; B, idiosoma, ventral; C, gnathosoma, ventral; D, epimeral plate lII anterior to insertion of leg III, with funnel-shaped structure; E, leg 1, ventral. Scale = 50 µm (A–C, E), scale = 10 µm (D).

Dampier Archipelago. Such a difference is common within ovigerous halacarid females, depending on the number and size of eggs. The difference in the length:width ratio of the gnathosoma (0.66 in the specimen from the Great Barrier Reef vs 0.79 in the one from Dampier) most likely is due to compression of the holotype.

Marginal cavities on the PE, anterior to the insertions of legs III and IV, have not been described before. They are also present in two paratype females (Zoological Museum in Hamburg A57/00) from the Great Barrier Reef.

Distribution

Scaptognathus exquisitus seems to be widespread along the coast of tropical Australia; records are from eastern Australia, from 19 to 14°S, and western Australia, at 20°S, from sandy deposits at a depth range of 0.5 to 10 m.

Subfamily Simognathinae Viets, 1927

Genus *Simognathus* Trouessart, 1889

Simognathus platyaspis Otto, 2000

Figure 9A–E

Simognathus platyaspis Otto, 2000a: 519–521, figures 14A–D, 15A–D.

Material Examined

Australia: Western Australia: 1 female, Burrup Peninsula, Watering Cove, 20°35'S, 116°58'E, coral block, low water edge, 1 August, 2000, coll. I. Bartsch (WAM T52105).

Diagnosis

Idiosomal length 315 µm, width 170 µm. Dorsal plates uniformly foveate, integument delicately punctate. Posterior two-third of AD with brown pigmentation. AD longer than PD (Figure 9A). OC triangular. AD with hyaline lens, OC with cornea. Ventral plates almost uniformly foveate except for (1) a portion immediately posterior to camerostome, (2) anterior portion of GA and (3) around GO (Figure 9B). GA with four pairs of pgs. Adanal setae in ventral position. Ventral flank of gnathosoma foveate. Triangular lamella forming a tectum (Figure 9C). Second palpal segment with ventral protuberance and one long seta (Figure 9D). Tibiae club-shaped. Leg chaetotaxy (solenidia omitted, pas included): leg I, 1, 2, 2, 4, 5, 6; leg II, 1, 2, 3, 4, 5, 6; legs III and IV, 1, 1, 2, 3, 5, 5. Ventral seta of tibia I basally wide, with apophysis, then tapering (Figure

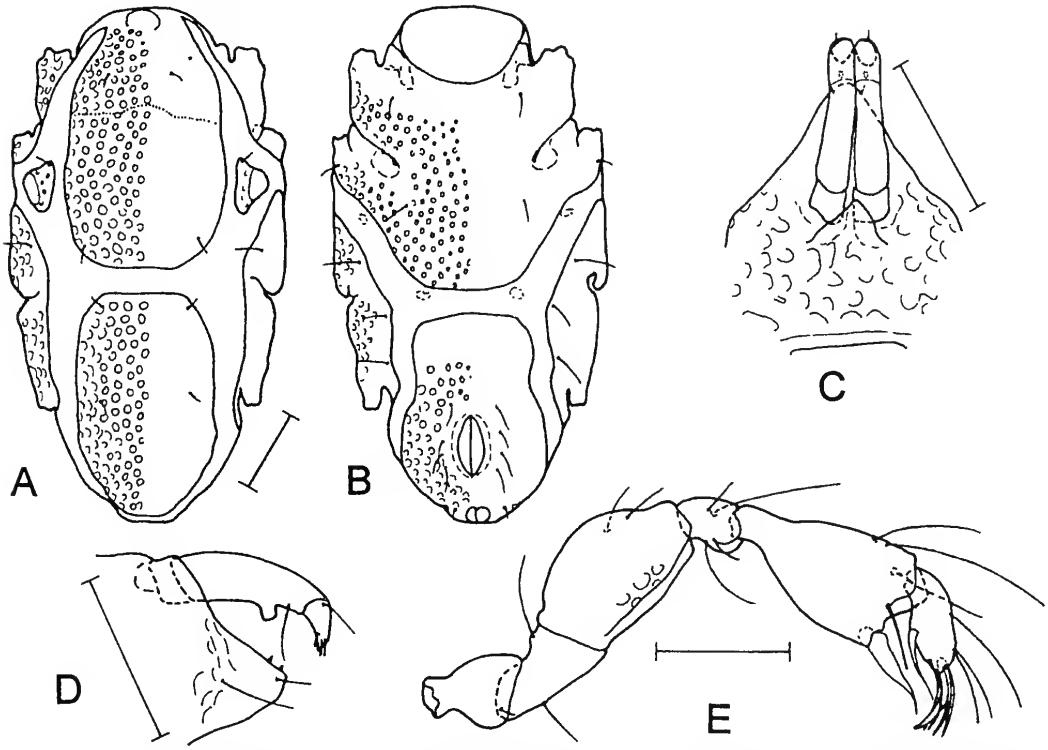


Figure 9 A–F. *Simognathus platyaspis* Otto, 2000, female. A, Idiosoma, dorsal (stippled line along margin of brown pigmentation); B, idiosoma, ventral; C, part of gnathosoma, dorsal; D, part of gnathosoma, lateral; D, leg I, medial. Scale = 50 µm.

9E). Pair of ventral spines of tibiae II coarsely pectinate, that pair of spines on tibiae III and IV only slightly pectinate. Tarsi I and II each with three dorsal setae, one ventral seta and pair of single eupathid pas. Tarsi III and IV each with three dorsal setae, one ventral seta and medial pas. Tarsus I with large median claw and slender paired claws. Paired claws of tarsi II to IV with accessory process, else smooth; central sclerite with small process.

Remarks

Similarly shaped and pigmented plates and the same outline of palps and tibiae are present in *S. maculatus* Bartsch, 1994, *S. specialis* Otto, 2000, *S. versicolor* Otto, 2000, and *S. xandarus* Otto, 2000, all from Australia, in *S. glareus* Bartsch, 1985 from New Zealand, in *S. latitarsus* Proches, 2002 from South Africa, in *S. obtusus* Newell, 1971 and *S. subobtusus* Newell, 1984 from off Chile, and in *S. fuscus* Viets, 1936, recorded from the Caribbean (Viets, 1936; Newell, 1971, 1984; Bartsch, 1985b, 1994a; Otto, 2000a; Proches 2002).

In the just mentioned Australian species, as also in *S. latitarsus*, the foveate ornamentation of the AE is restricted to the lateral margins, ventrally the plate is uniformly punctate. In contrast, in *S. platyaspis* the AE is almost uniformly foveate. Females of the three southern Pacific species, *S. glareus*, *S. obtusus* and *S. subobtusus*, have a small PD and the ds-4 are situated within the membraneous integument, whereas in *S. platyaspis* that pair of setae is on the PD. Moreover, in *S. glareus* and *S. subobtusus* the paired claws on tarsus I are much more stout than in *S. platyaspis*, and female *S. obtusus* have a shorter GA relative to the size of GO.

Simognathus fuscus, a species from Bonaire (Viets, 1936), resembles *S. platyaspis* in shape and ornamentation. Otto (2000a) used the length:width ratio of the AD for discrimination, a quotient that can be influenced by the mounting procedure. The paratype of *S. platyaspis*, housed in the Zoological Museum in Hamburg, Germany (ZMH A3/01), is squeezed and the holotype (not seen by the author) is suspected to be deformed, too. The length:width ratio of the AD in the present specimen of *S. platyaspis* is 1.65, that of the holotype of *S. fuscus* 1.69, hence almost the same. The rostrum of *S. fuscus* is very short, about one fifth of the length of the gnathosoma, but one fourth in *S. platyaspis*.

Distribution

Tropical Australia, Great Barrier Reef, 1–6 m, coarse sand and coral rubble (Otto, 2000a) and Dampier area (present record). Not bound to sandy deposits.

Simognathus salebrosus sp. nov.

Figures 10A–J, 11A–F

Material Examined

Holotype

Male, Burrup Peninsula, east coast, King Bay, 20°38'S, 116°45'E, sandy tidal bank in a small river emptying into King Bay, Western Australia, Australia; 25 July 2000, coll. I. Bartsch (WAM T52106).

Other Material Examined

Australia: Western Australia: 1 female, Dampier, 20°39'S, 116°42'E, sandy flat, lower part of tidal slope, 1 August 2000, coll. I. Bartsch (WAM T52107).

Etymology

Derived from Latin salebrosus, rough, uneven, because of the rough surface of the plates.

Diagnosis

Idiosomal length 364–398 µm. AD and PD with delicate punctation, their surface uniformly foveate. AD longer than PD. OC elongate, covered by membraneous integument. AE and GA fused. Plates foveate apart from area representing anterior part of GA. AE with large marginal epimeral fossae. Area of epimera II and PE contiguous; lateral GA and posterior part of PE almost articulating. Female GA with four pairs of pgs. Male GA with three pairs of outlying pgs and 26 pgs arranged in a ring close around GO. Gnathosomal base dorsally and marginally foveate; with triangular lamelliform tectum. Palps short. Trochanter I large, with small cylindrical base. Tibia I widest in basal third, then evenly tapering. Posterior part of tibia I rotated relative to axis of the leg. Tarsus I short, 0.17 of length of tibia. Tarsi I to IV with 1, 1, 1, 1 ventral setae and 2, 2, 1, 1 pas, respectively. Pectines of claws of tarsi II to IV with numerous short tines.

Description

Male

Idiosoma. Male. Length 364 µm, width 189 µm. AD and PD with intense punctation and superficial foveae. Length of AD 167 µm, width 130 µm; anterior margin undulate due to foveae (Figure 10A), posterior margin truncate. AD with ds-1 and ds-3 as illustrated. OC reduced to short, elongate sclerite which is covered by striae of membraneous integument; its length 22 µm, width 7 µm. PD slightly longer than AD, its length 175 µm, width 130 µm; anterior margin truncate. Pairs of ds-4 and ds-5 slightly posterior to the level of insertions of legs III and IV, respectively. Pair of ds-6 in marginal position.

Ventral plates evenly punctate and foveate; foveae absent posterior to camerostome, in an area representing anterior part of GA and around GO

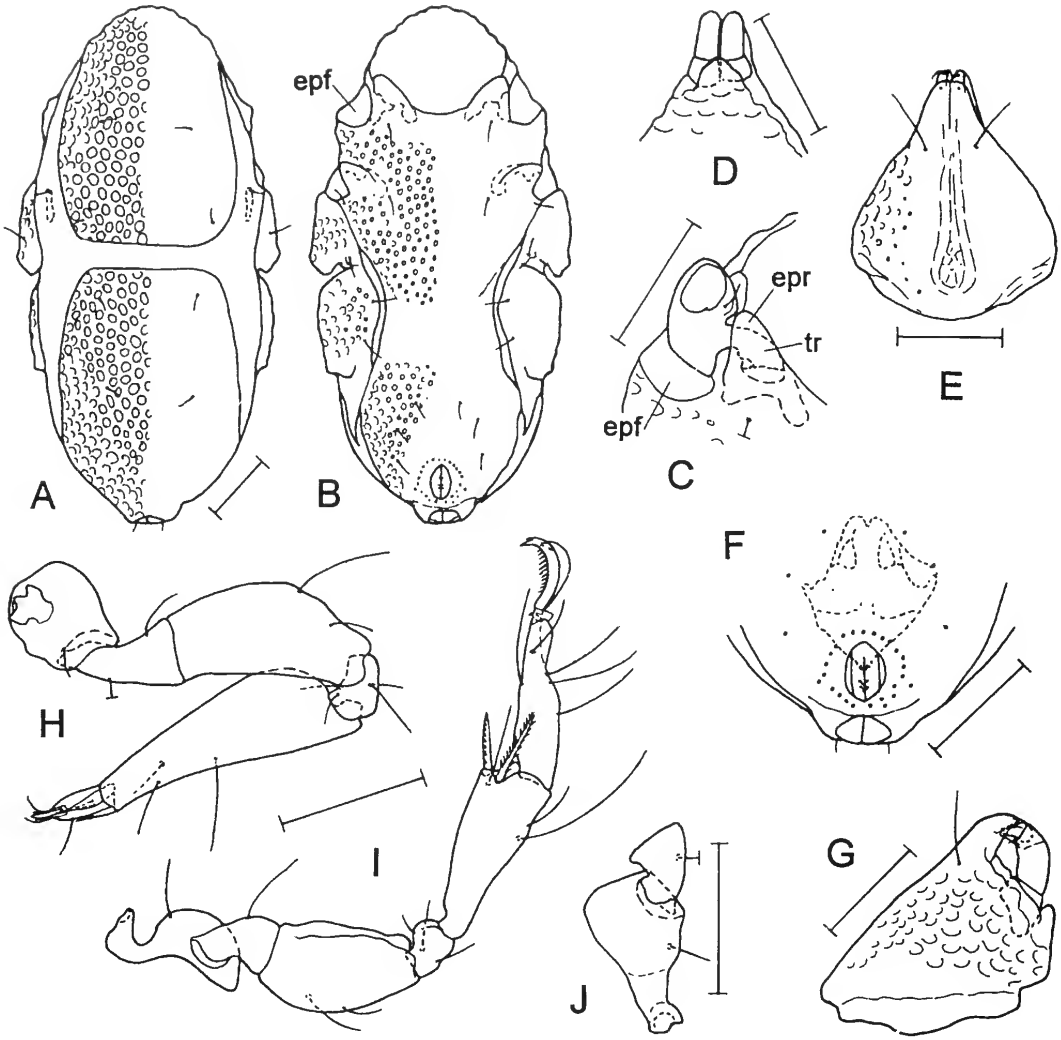


Figure 10 A–F. *Simognathus salebrosus* sp. nov. A, Idiosoma, dorsal, male; B, idiosoma, ventral, male; C, epimeral plate with fossa and trochanter I, female; D, tectum, male; E, gnathosoma, ventral, male; F, genital area, male; G, gnathosoma, lateral, female; H, leg I, medial and ventral, male; I, leg III, medial (trochanter in ventral aspect), male; J, trochanter and basifemur III, medial, female. Scale = 50 µm (epf, epimeral fossa; epr, epimeral process; tr, trochanter).

(Figure 10B). AE and GA fused to a ventral shield; its length 289 µm, width 164 µm. Epimera II and PE as well as posterior part of PE and lateral GA contiguous. Epimeral processes I to IV forming large lamellae. Anterior epimera with large marginal fossae lateral to insertions of legs I (Figure 10C) and II. AE with three pairs of setae and rather small epimeral vesicles. PE extending posteriad beyond insertion of leg IV. GO small, length 45 µm, width 27 µm, situated close to posterior margin of idiosoma. GA with three pairs of outlying pgs and 26 pgs arranged in a ring close around GO. Genital sclerites with three pairs of sgs (Figure 10F).

Gnathosoma. Length 115 µm, width 99 µm. Gnathosomal base dorsally and marginally foveate (Figure 10G), median part of ventral flank almost smooth (Figure 10E). Dorsum with lamellar, triangular tectum (Figure 10D). Basal pair of maxillary setae long, distal pair short, slender. Palps short, three-segmented. Second segment with ventral seta but without protuberance; delicate incision may represent fusion between P-2 and P-3.

Legs I to IV rather similar in length. Base of trochanters I and II cylindrical, bent in an almost right angle to longitudinal axis of the legs (Figure 10C). Trochanters III and IV elongate, almost as

long as telofemora. Telofemora III and IV longer than tibiae. Tibia I with cylindrical base, abruptly expanding at 0.28 (relative to length of tibia), then evenly tapering (Figure 10H). Posterior portion rotated so that the ventral seta is in a medial position. Tibiae II to IV claviform (Figures 10I, 11B and C). Tarsus I very short, hardly longer than high, its median claw turned inward (Figure 11D and E). Tarsi II to IV at least three times longer than high. Leg chaetotaxy (solenidia omitted, pas included): leg I, 1, 2, 2, 4, 5, 6; leg II, 1, 2, 3, 4, 5, 6; legs III and IV, 1, 1, 2, 3, 5, 5. Ventral spine of tibia I stout, bluntly ending, without basal apophysis (Figure 11D); medial seta slender, flagelliform. Tibiae II to IV with pair of wide, roughly bipectinate ventral setae. Tarsi I to IV with three dorsal fossary setae; on tarsus I dorsomedial fossary seta shorter than dorsolateral one; on tarsi II to IV paired fossary setae delicately serrate. Tarsi I to IV each with long ventral seta, that seta on tarsus I basally wide, then tapering, on tarsi II to IV ventral seta delicately serrate. Tarsi I and II each with pair of pas, tarsi III and IV with medial pas. Solenidion of tarsus I setiform, famulus lamellar. Solenidion of tarsus II setiform, situated on inside of medial fossa membrane (Figure 11F).

Tarsus I with median claw and very slender paired claws, these claws smooth. Paired claws of tarsi II to IV large, with accessory process and pectines; central sclerite minute, without distinct claw-like process.

Female

Dorsal aspect resembling that of male. AE and GA fused. GA with four pairs of pgs (Figure 11A).

Remarks

Simognathus salebrosus is strikingly similar to *S. abnormalus* Otto, 2000 and *S. scutatus* Bartsch, 1993, species recorded from the Great Barrier Reef, Queensland and Rottnest Island, Western Australia, respectively (Otto, 2000a; Bartsch, 1993), the three species have a ventral shield, short tarsus I and a short palp which lacks a protuberance. *S. scutatus* is easily distinguished from the others because all ventral plates are fused, both in the female and male, and its tibia I is almost equal in height for most of its length. In contrast to males of *S. abnormalus*, which bear two pairs of outlying setae, the single male of *S. salebrosus* has three pairs of such setae. The female GA and PE of *S. salebrosus*

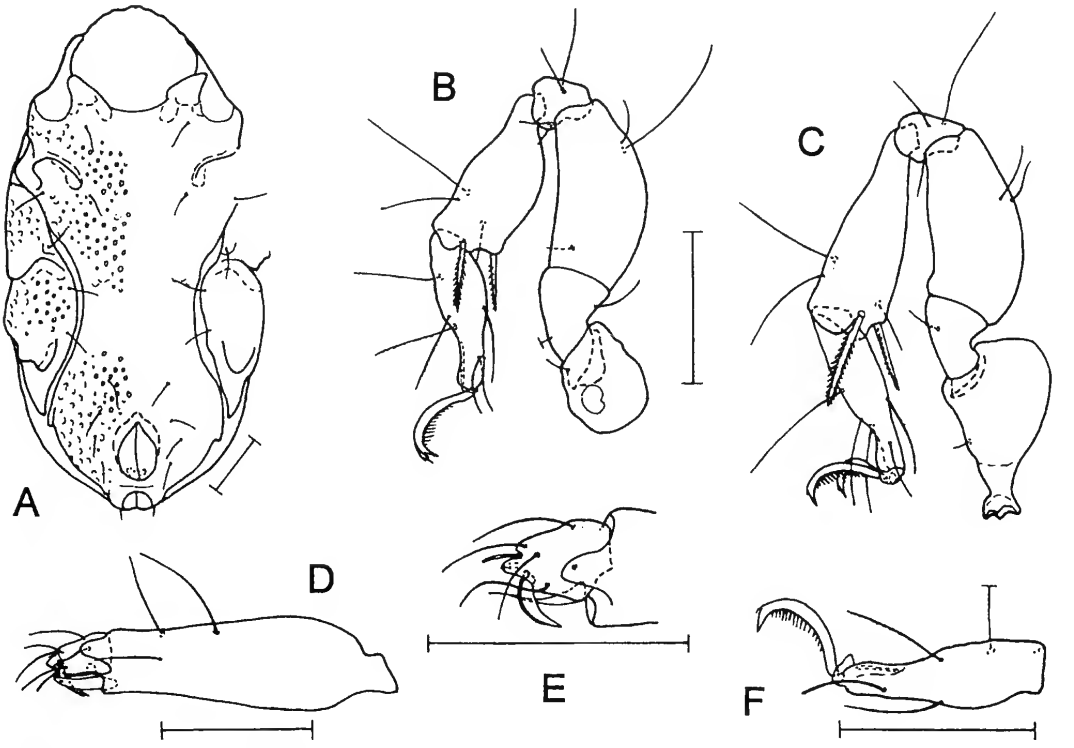


Figure 11 A–F. *Simognathus salebrosus* sp. nov. A, Idiosoma, ventral, female; B, leg II, medial, female; C, leg IV, medial, female; D, tibia and tarsus I, medial, female; E, posterior part of tibia and tarsus I, medial, female (ventromedial seta and ventral spine of tibia omitted, lateral pas and claw omitted); F, tarsus II, medial, female (lateral pas and claw omitted). Scale = 50 µm.

are almost contiguous but not fused. In *S. abnormalus* variants are known with the GA and PE either fused or separated (Otto, 2000a). *Simognathus salebrosus* and *S. abnormalus* differ in that in the former species the AD is foveate throughout, in *S. abnormalus* the anterolateral portions are non-foveate.

With the shape of leg I, the tibia being highest in the basal third, then tapering towards the rotated distal portion, and a very short tarsus, this *Simognathus* resembles *Acaromantis* species. The three-segmented palps and the presence of paired claws associated with the median claw are characters of the genus *Simognathus*.

Conspicuous of *S. salebrosus*, and also of *S. abnormalus*, is that epimera I and II form large marginal fossae. The distal part of trochanters I and II are within these epimeral fossae while the articulation of the trochanters is protected by the epimeral processes.

Distribution

Indian Ocean, Western Australia, Dampier. From a tidal beach area.

Simognathus tener sp. nov.

Figures 12A–J, 13A–D

Material Examined

Holotype

Male, Dampier, 20°39'S, 116°42'E, Western Australia, Australia; beach in recreation area, coarse

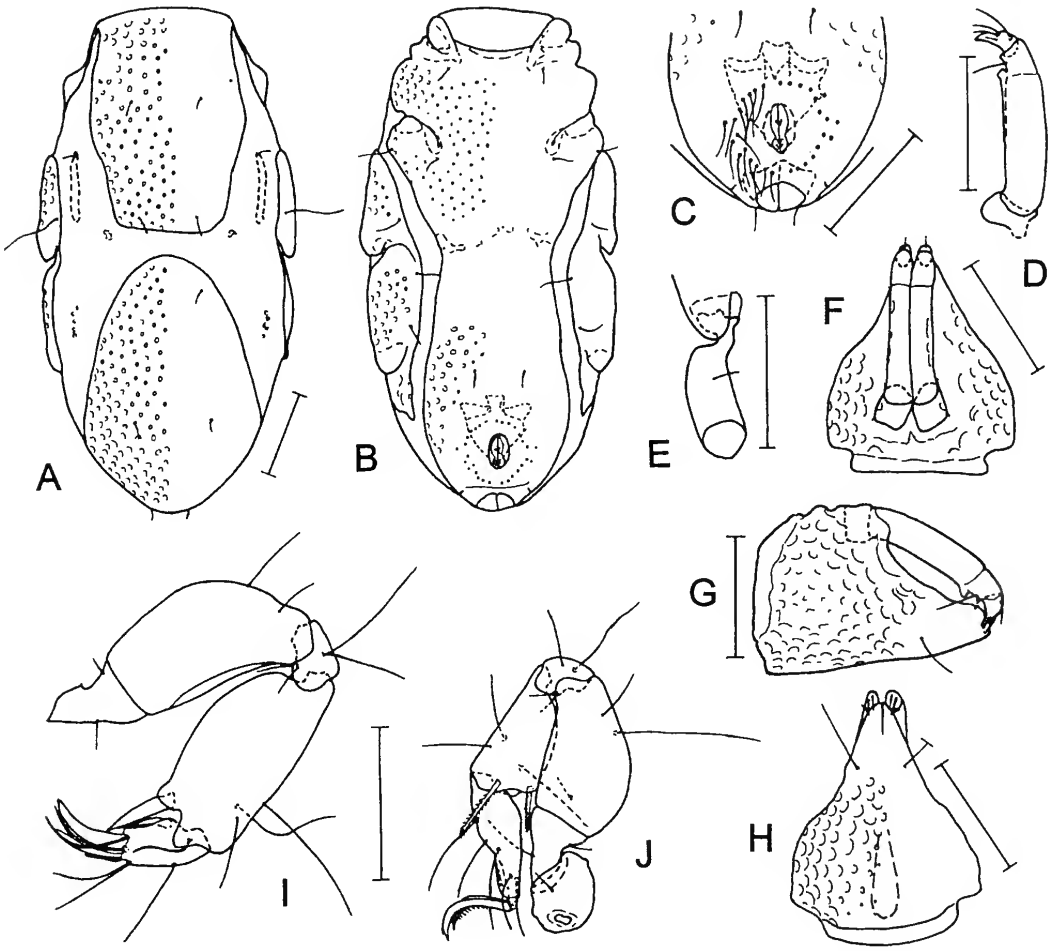


Figure 12 A–J. *Simognathus tener* sp. nov. A, Idiosoma, dorsal, male; B, idiosoma, ventral, male; C, genital area, male; D, palp, medial, female; E, insertion of trochanter IV, ventral, male; F, gnathosoma, dorsal, male; G, gnathosoma, lateral, female; H, gnathosoma, ventral, male; I, basifemur to tarsus I, medial, male; J, leg II, medial, male. Scale = 50 µm.

sand, mid-tide, 0–3 cm sediment depth, 3 August 2000, coll. I. Bartsch (WAM T52108).

Paratype

Australia: Western Australia: 1 female, collecting data same as above (WAM T52109).

Etymology

Specific name derived from tener, Latin, delicate, referring to the delicate ornamentation of the plates.

Diagnosis

Idiosomal length 290–320 µm. Dorsal plates punctate, surface with small, faint foveae. AD shorter than PD. OC elongate, covered by membraneous integument. Anterior margin of PD ovate. AE and GA fused to elongate ventral shield; its surface covered by very delicate foveae. Foveae absent in area representing anterior portion of GA. Gnathosomal base foveate. Dorsum with raised cuticular markings, but without a dorsal lamella extending beyond base of palps. Palps long, more than half of idiosomal length. Second palpal segment elongate, with ventral protuberance, seta and an apical triangular lamella. Length of tibia I twice its height. Ventral spine on tibia I long, evenly tapering. Tarsi II to IV with six setae each, parambulacral setae included (solenidia omitted).

Description

Male

Idiosoma. Male. Length 290 µm, width 150 µm; length:width ratio 1.9. Dorsal plates evenly punctate, surface with delicate foveae (Figure 12A). Length of AD 130 µm, width 92 µm; posterior margin truncate. Gland pores tiny, near lateral margin. AD with ds-1 and ds-3, the latter removed from lateral margin of plate. Pair of ds-2 on OC which is hidden beneath striae of membraneous integument. Length of PD 147 µm, width 102 µm; anterior margin ovate. PD with ds-4 and ds-5 (in holotype one of ds-4 lacking). Setae ds-6 in marginal position.

Ventral plates evenly punctate; surface largely covered by small, delicate foveae; these foveae absent in an area representing anterior part of GA and around GO (Figure 12B). AE and GA fused to a ventral shield; its length 263 µm, width 122 µm. Epimeral processes I to IV forming large lamellae (Figures 12B and E). PE extending posteriad beyond insertion of leg IV. AE with three pairs of setae; the two posterior ones at almost the same level. GO small, length 20 µm, width 12 µm. GA with one pair of outlying setae and 31 slender setae around GO. Spermatopositor extending beyond ring of pgs (Figure 12C).

Gnathosoma. Coarsely foveate (Figures 12F–H); its length 97 µm, width 75 µm. Dorsum of gnathosomal base roughly textured, without lamelliform tectum (Figure 12F); pair of lateral lamella enclosing P-1 (Figure 12G). Palps slender; second palpal segment long, about 0.6 of gnathosomal length; segment with ventromedial lamella and protuberance (Figure 12D), strong ventral seta, and triangular, distolateral lamella. The latter discernible in dorsolateral aspect.

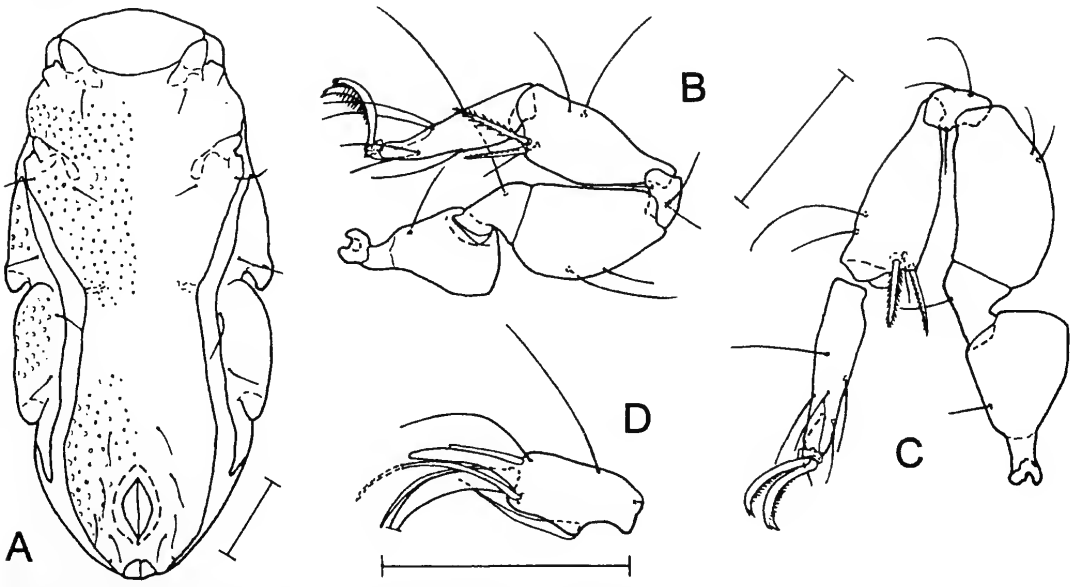


Figure 13 A–D. *Simognathus tener* sp. nov. A, Idiosoma, ventral, female; B, leg III, medial, female; C, leg IV, medial, female; D, tarsus I, lateral (medial setae and claw omitted, lateral pas in holotype broken), male. Scale = 50 µm.

Legs. Telofemur and tibia I almost equal in length. Tibia II shorter than telofemur II. Base of tibia I cylindrical, then abruptly widened and almost equal in height in posterior half of segment (Figure 12I). Tibiae II to IV clavate (Figures 12J, 13B and C). Leg chaetotaxy (pas included, solenidion excluded): leg I, 1, 2, 2, 4, 5, 6; leg II, 1, 2, 3, 4, 5, 6; legs III and IV, 1, 1, 2, 3, 5, 6. Ventral spine of tibia I without basal apophysis but evenly tapering; medial seta flagellate. Tibiae II to IV each with two coarsely bipectinate setae. Each of tarsi I to IV with three dorsal setae, one ventral seta and a pair of pas. That ventral seta on tarsus I basally stout, then tapering. Solenidion of tarsus I setiform, famulus lamelliform (Figure 13D).

Median claw on tarsus I large, smooth, paired claws similar in length but slender, resembling parambulacral setae. Paired claws of tarsi II to IV with pectines, each with numerous tines.

Female

Length 320 µm. Dorsal aspect resembling that of male. Ventral plates AE and GA fused (Figure 13A). GA with four pairs of pgs.

Remarks

Simognathus tener and *S. aspidiotus* Otto, 2000 share numerous characters, the AE and GA form a ventral shield; the males have a single pair of outlying setae, the palps are long and slender, the second segment is provided with a protuberance and distal lamella; tarsi II to IV each bear one ventral seta and a pair of pas. *Simognathus tener* has more slender dorsal plates and more delicate foveae than *S. aspidiotus*.

Species with a ventral shield are *S. abnormalus*, *S. aspidiotus* Otto, 2000, *S. clypeatus* Otto, 2000, *S. gibberosus* Bartsch, 1994, *S. salebrosus*, *S. scutatus* Bartsch, 1993, *S. tener*, *S. tropicalis* Chatterjee & de Troch, 2000, and *S. uniscutatus* Bartsch, 1994 (Bartsch 1993, 1994a; Chatterjee & de Troch, 2000; Otto, 2000a).

In contrast to the other above species, the AD of *S. gibberosus* bears a hyaline lens. *S. abnormalus* and *S. salebrosus* have an *Acaromantis*-like tibia I, elongate and rotated. In *S. scutatus* all ventral plates are fused, there are no striae of membraneous integument between AE and PE. Tarsi III and IV of *S. uniscutatus* have a ventral seta and a single pas, the medial but no lateral pas. In contrast, tarsi III and IV of *S. aspidiotus*, *S. clypeatus* and *S. tener* each bear a ventral seta and both a medial and lateral pas; in *S. clypeatus* one of the pas is doubled. The three species can be separated on the base of the ornamentation of the dorsal and ventral plates; the ventral plates are almost smooth in *S. clypeatus*, delicately foveate in *S. tener* and coarsely foveate in *S. aspidiotus*. The description of *S. tropicalis*, by Chatterjee & de Troch (2000), presents no information on the arrangement and number of the pas.

According to Otto (2000a), the male of *S. gibberosus* (housed in the WAM) has the AE and GA separated. A re-examination of that male showed that the AE and GA are fused to a ventral shield but there is a rupture. Most likely, the slide had been pressed seriously, a pressure and distortion which caused a split in the integument of the mite which was soaked and hardened by the mounting medium (glycerin jelly). The rupture largely follows the borders of the relevant plates. Hence, according to present knowledge, males of *S. gibberosus* have a ventral shield.

Distribution

Indian Ocean, Western Australia, Dampier. From a tidal beach.

Simognathus uniscutatus Bartsch, 1994

Figure 14A–D

Simognathus uniscutatus Bartsch, 1994a: 145, figures 45–52.

Material Examined

Australia: Western Australia: 1 female, Enderby Island, West of Rocky Head, 20°32.1'S, 116°26.7'E, sponge garden, 2–13 m, unsorted sandy deposits, 3 August 2000, coll. C. Bryce (WAM T52110).

Diagnosis

Idiosomal length 390 µm. Dorsal plates densely punctate and distinctly foveate. AD shorter than PD (Figure 14A). Anterior margin of PD truncate. OC reduced to oblong sclerite beneath striae of integument. Pair of ds-2 in anterior edge of that platelet. AE and GA fused (Figure 14B). This ventral shield with small foveae except for a smooth median portion representing anterior part of GA. AE with large epimeral processes. Female GA with four pairs of sgs. Gnathosomal base foveate; dorsally with raised cuticular ornamentation but without tectum-like lamella (Figure 14C). Second palpal segment elongate, with ventral protuberance, a seta and a triangular lamella. Leg chaetotaxy (solenidia omitted, pas included): leg I , 1, 2, 2, 4, 5, 6; leg II, 1, 2, 3, 4, 5, 6; legs III and IV, 1, 1, 2, 3, 5, 5. Tibia I short, with cylindrical base, then conspicuously widened (Figure 14D); its ventral spine evenly tapering, without apophysis. Pair of ventral spines on tibiae II to IV distinctly bipectinate. Tarsi I and II each with a wide ventral seta and a pair of eupathid pas; tarsi III and IV with a ventral seta and a single medial pas. On tarsus IV ventral seta and pas situated almost adjacent. Tarsus I with large median and slender paired claws. Paired claws of the following legs with coarsely dentate pectines. Central sclerite with small process.

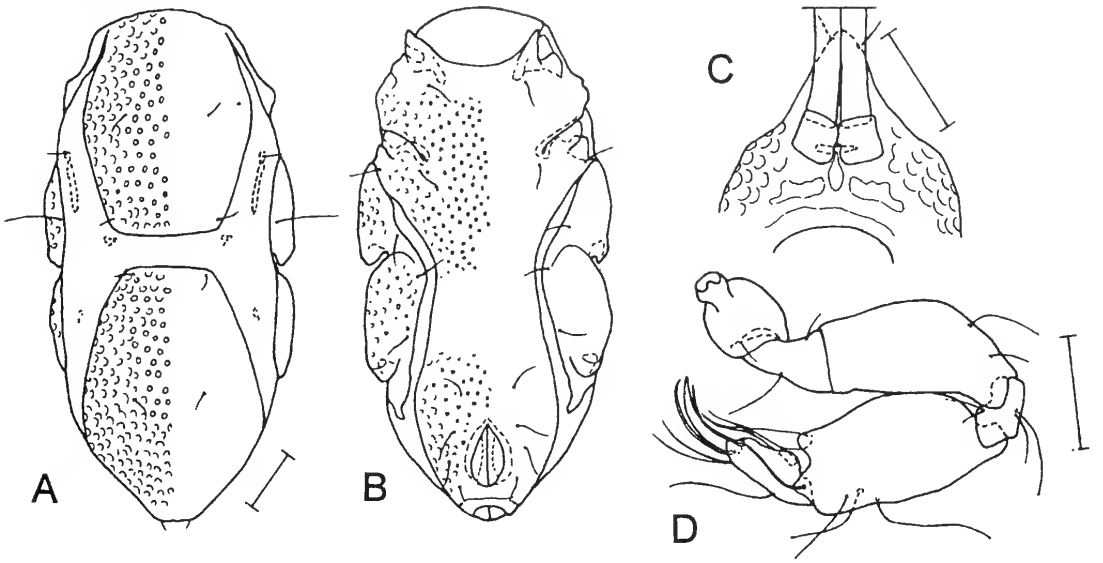


Figure 14 A–F. *Simognathus uniscutatus* Bartsch, 1994, female. A, Idiosoma, dorsal; B, idiosoma, ventral; C, part of gnathosoma, dorsal; D, leg I, medial. Scale = 50 µm.

Remarks

The present female is larger than the holotype female from Rottnest Island, Western Australia (390 µm vs 322 µm) and basifemur I bears two instead of three setae, as present in the holotype of *Simognathus uniscutatus*. Two setae on basifemur I is the usual number in the majority of *Simognathus* species and the presence of three setae is expected to be an anomaly and of no taxonomic relevance.

Distribution

Western Australia, Rottnest Island and Dampier.

FAUNAL COMPARISON

From Australia, information on psammophilous halacarid species is available from Rottnest Island and Dampier, Western Australia, and the Great Barrier Reef Marine Park and Coral Sea, Queensland. Though the data sets are far from complete, a preliminary comparison of the faunas can be made.

Rottnest Island, at a latitude of about 32°S, is characterized by numerous sandy beaches separated by limestone platforms. The beaches, with different exposure to waves and currents, demonstrate a variety of grain size composition. Rottnest Island lies in a transition zone between the warm-temperate and tropical zone (Wells and Walker, 1993).

Dampier is in the tropical arid zone, at about 20°S. The coastline is dominated by muddy and silty flats or mud-covered rocky platforms in the mid- and lower tidal zone, rocks, boulders and mangroves in the higher tidal area. Sandy deposits with coarse and medium-sized grains are rare. The subtidal sediment immediately off Dampier is rich in organic material but around the outer islands of the Dampier Archipelago there are coarse sediments.

The tropical Great Barrier Reef Marine Park and adjacent Coral Sea cover a latitudinal area from about 14° to 21°S. There is a variety of different substrata, amongst others areas with fine to coarse sand and coral rubble.

The number and extent of collections performed in the three areas Rottnest Island, Dampier and Great Barrier Reef vary from sampling just once, during a short stay of about two and a half weeks (Rottnest Island, Dampier) to numerous collections taken in a period of about two years (Great Barrier Reef). Additional species (Table 1) are expected to be found in all three areas.

Table 1 Halacarid genera and number of psammophilous species recorded from the Dampier area, Rottnest Island, the Great Barrier Reef and Coral Sea.

	Dampier	Rottnest Island	Great Barrier Reef, Coral Sea
Actacarus	2	2	4
Anomalohalacarus	1	1	0
Arhodeoporus	1	2	7
Copidognathus	1	7	14
Scaptognathides	2	1	3
Scaptognathus	1	2	8
Simognathus	4	7	12

Table 2 Psammophilous halacarid species from Dampier area and notes on records from other areas. +, record; –, no record

Dampier	Other areas
Actacarus pacificus	+ (Rottnest I., Hokkaido, Hawaiian Is, Robinson Crusoe I.)
Actacarus festivus	–
Anomalohalacarus dampierensis	–
Arhodeoporus corallicolus	+ (Great Barrier Reef)
Copidognathus meridianus	–
Scaptognathides hawaiiensis	+ (southern China, Hawaiian Is)
Scaptognathides ornatus	+ (Hawaiian Is)
Scaptognathus exquisitus	+ (Great Barrier Reef)
Simognathus salebrosus	–
Simognathus platyaspis	+ (Great Barrier Reef)
Simognathus tener	–
Simognathus uniscutatus	+ (Rottnest I.)

In the Dampier area, the collection from sandy deposits and coral fragments contained 12 species, seven of them have been recorded previously from other areas, two species from the Indian and six from the Pacific Ocean and adjacent basins, three from the Great Barrier Reef and three from the Hawaiian Islands (Table 2). The data on the psammobiont halacarid fauna corroborates an assumption of the presence of a rather uniform tropical coastal fauna from North West Cape across the northern Australian coastline to Queensland and also to the Hawaiian Islands. Yet, because of the small size of psammobiont halacarids and hence difficulties in recognizing details, the presence of cryptic species cannot be excluded. Studies on the tidal rhombognathine halacarids from Dampier also demonstrated close similarities with the fauna of the northeastern Australia (Bartsch, 2003a).

ACKNOWLEDGEMENTS

The samples were taken in July and August 2000 during the Woodside Dampier Marine Biological Workshop which was organized by Dr Fred Wells and Di Jones, Western Australian Museum, and Prof. Diana Walker, The University of Western Australia. Clay Bryce provided me with subtidal sediments from the outer islands. The workshop was sponsored by Woodside Energy Ltd and accomodation was provided by Hamersley Iron Pty. Ltd. My flight to Australia was financed by the German Research Foundation (DFG). Dr H. Dastych arranged loan of specimens housed in the Zoological Institute and Zoological Museum in Hamburg. To all my sincerest thanks.

REFERENCES

Abé, H. (1996). A new species of the genus *Anomalohalacarus* (Acari: Halacaridae) from Japan with notes on taxonomic characters. *Journal of the Acarological Society of Japan* **5**: 7–16.

Abé, H. (1997). Halacarid mites of the genus *Actacarus* (Acari: Halacaridae) from Hokkaido, Northern Japan. *Species Diversity* **2**: 31–42.

Bartsch, I. (1976a). Beitrag zur Halacariden-Fauna (Halacaridae, Acari) der Bretagneküste. Beschreibung von fünf Arten aus dem Sandlückensystem. *Acarologia* **17**: 652–667.

Bartsch, I. (1976b). Ergänzungen zur Halacariden-Fauna (Halacaridae, Acari) im Becken von Arcachon. *Vie et Milieu, série A* **26**: 31–46.

Bartsch, I. (1979). Halacaridae (Acari) from Oahu Island (Hawaiian Archipelago). *Entomologische Mitteilungen aus dem Zoologischen Museum Hamburg* **6**: 231–241.

Bartsch, I. (1981a). Halacaridae (Acari) aus dem Kanal von Moçambique. *Cahiers de Biologie marine* **22**: 35–63.

Bartsch, I. (1981b). Die Gattungen *Anomalohalacarus* und *Halacaroides* (Halacaridae, Acari), geographische Verbreitung, Bestimmnungstabelle und Beschreibung dreier neuer Arten. *Zoologische Beiträge, Neue Folge* **27**: 67–84.

Bartsch, I. (1982). Weitere Halacaridae (Acari) aus dem Kanal von Moçambique. *Cahiers de Biologie marine* **23**: 435–457.

Bartsch, I. (1985a). Notes on the Halacaridae (Acari) of Yorkshire. *Naturalist* **110**: 41–48.

Bartsch, I. (1985b). New species of Halacaridae (Acari) from New Zealand. *New Zealand Journal of Zoology* **12**: 175–185.

Bartsch, I. (1988). Arenicolous Halacaridae (Acari) in Hawaiian waters. *Proceedings, Hawaiian Entomological Society* **28**: 213–228.

Bartsch, I. (1991a). Taxonomic notes on halacarids (Acari) from the Skagerrak area. *Helgoländer Meeresuntersuchungen* **54**: 97–106.

Bartsch, I. (1991b). *Arhodeoporus mactanus* n. sp., a new species of marine mite (Acari, Halacaridae), from the Philippines. *The Philippine Journal of Science* **120**: 21–25.

Bartsch, I. (1991c). Arenicolous Halacaridae (Acari) from Hong Kong. *Asian Marine Biology* **8**: 57–75.

Bartsch, I. (1993). Arenicolous Halacaridae (Acari) from Rottnest Island, Western Australia, *In* F.E. Wells, D.I. Walker, H. Kirkman and R. Lethbridge (eds), *The Marine Flora and Fauna of Rottnest Island, Western Australia*: 73–103.

Bartsch, I. (1994a). The genus *Simognathus* (Acari, Halacaridae), description of six new species from southern Australia and a tabular key to all species. *Acarologia* **35**: 135–152.

Bartsch, I. (1994b). *Copidognathus* (Halacaridae: Acari) from Western Australia. Description of twelve species of the *gibbus* group. *Records of the Western Australian Museum* **16**: 535–566.

Bartsch, I. (2000). Rhombognathinae (Acari: Halacaridae) from the Great Barrier Reef, Australia. *Memoirs of the Queensland Museum* **45**: 165–203.

Bartsch, I. (2003a). Rhombognathine mites (Halacaridae: Acari) from Dampier, Western Australia: taxonomy and biogeography. *In* F. E. Wells, D. I. Walker and D.

Jones (eds), *Proceedings of the Eleventh International Marine Biological Workshop: The Marine Flora and Fauna of Dampier; Western Australia* (in press)

Bartsch, I. (2003b). A new arenicolous *Copidognathus* (Halacaridae: Acari) from Dampier, Western Australia, *In* F. E. Wells, D. I.Walker and D. Jones (eds), *Proceedings of the Eleventh International Marine Biological Workshop: The Marine Flora and Fauna of Dampier; Western Australia* (in press)

Chatterjee, T. and de Troch, M. (2000). Halacaridae (Acari) from Gazi Bay (Kenya): description and biogeography of three new and two known species. *Hydrobiologia* **427**: 177–194.

Krantz, G.W. (1971). The mites of Quintana Roo. II. *Actacarus giganteus*, a new species of arenicolous mite (Prostigmata: Halacaridae) from the Caribbean coast. *Annals of Entomological Society of America* **64**: 594–598.

Monniot, F. (1967). Deux halacariens endopsammiques: *Halacarus anomalus* Trouessart 1894 et *Halacarus marcandrei* n. sp. *Cahiers de Biologie Marine* **8**: 89–98.

Morselli, I. & Mari, M. (1981). *Anomalohalacarus affinis* n. sp., un alacaride (Halacaridae: Acari) delle coste Toscane. *Atti della Societa Toscana di Scienze Naturali, Memorie, Serie B* **87**: 275–283.

Morselli, I. & Mari, M. (1982). Alacaride (Acari, Prostigmata) di fondi sabbiosi della costa Ionica del Salento. *Atti della Societa Toscana di Scienze Naturali, Memorie, Serie B* **88**: 229–247.

Morselli, I. and Mari, M. (1989). Halacarids (Halacaridae: Acari) of the Leghorn coast. V. *Anomalohalacarus affinis*, a new interstitial infralittoral species. *Bolletino di Zoologia* **56**: 105–108.

Newell, I.M. (1971). Halacaridae (Acari) collected during cruise 17 of the R/V Anton Bruun, in the southeastern Pacific Ocean. *Anton Bruun Report* **8**: 3–58.

Newell, I.M. (1984). Antarctic Halacaroidea. *Antarctic Research Series* **40**: 1–284.

Nicholls, A.G. (1935). Copepods from the interstitial fauna of a sandy beach. *Journal of the Marine Biological Association of the United Kingdom* **20**: 379–405.

Otto, J.C. (1999a). Halacarid fauna of the Great Barrier Reef and Coral Sea: the genera *Agauopsis* and *Halacaropsis* (Acarina: Halacaridae). *Memoirs of the Queensland Museum* **43**: 797–817.

Otto, J.C. (1999b). *Corallihalacarus chilcottensis*, a new genus and species of marine mite from the Coral Sea (Acarina: Halacaridae). *Zoological Science* **16**: 839–843.

Otto, J.C. (2000a). Simognathinae (Acarina: Halacaridae) from the Great Barrier Reef and Coral Sea, description of thirteen new species. *Memoirs of the Queensland Museum* **45**: 505–534.

Otto, J.C. (2000b). Halacaridae from the Great Barrier Reef and Coral Sea: The genera *Lohmannella, Scaptognathides* and *Scaptognathus* (Acarina: Halacaridae: Lohmannellinae). *Memoirs of the Queensland Museum* **45**: 535–555.

Otto, J.C. (2000c). *Acarochelopodia* and *Actacarus* species (Acari: Halacaridae) from Australia, with remarks on *A. pacificus* and *A. orthotectus*. *Species Diversity* **5**: 111–127.

Otto, J.C. (2000d). *Australacarus* (Acari: Halacaridae) from northern Australia, with description of three new species. *Records of the Western Australian Museum* **20**: 103–114

Otto, J.C. (2000e). *Xenohalacarus longirostris* n.gen., n.sp., a marine mite (Acari: Halacaridae: Lohmannellinae) from Chilcott Islet, Australia. *International Journal of Acarology* **26**: 285–291.

Otto, J.C. (2000f). Six closely related species of the *Copidognathus gibbus* group (Acarina: Halacaridae) from north-eastern Australia. *Cahiers de Biologie marine* **41**: 223–232.

Otto, J.C. (2000g). Seven new species of *Arhodeoporus* (Acarina: Halacaridae) from the Great Barrier Reef and Coral Sea. *Hydrobiologia* **436**: 1–16.

Otto, J. (2001a). A new species of *Mictognathus* (Acari: Halacaridae) from the Great Barrier Reef. *Pacific Science* **55**: 43–46.

Otto, J. (2001b). Halacaridae of the Great Barrier Reef Lagoon and Coral Sea: *Halacarellus* and *Halacarus*. (Acarina: Halacaroidea). *Memoirs of the Queensland Museum* **46**: 691–716.

Otto, J. (2001c). Halacaridae of the Great Barrier Reef Lagoon and Coral Sea: The *Copidognathus ornatus* group (Acarina: Prostigmata: Halacaridae). *Memoirs of the Queensland Museum* **46**: 717–731

Otto, J.C. & Bartsch, I. (1999). *Tropihalacarus spio*, a new genus and species of Halacaridae (Acarina: Prostigmata) from the Great Barrier Reef. *Acarologia* **40**: 171–178.

Proches, S. (2002). The first records of the genus *Simognathus* (Acari:Halacaridae) from southern Africa, with a species description. *African Entomology* **10**: 354–356.

Rao, C.G. (1970). On some interstitial fauna in the marine sands on Indian coast. *Current Science* **39**: 504–507.

Remane, A. (1940). Einführung in die zoologische Ökologie der Nord- und Ostsee, *In* G. Grimpe and E. Wagler (eds), *Die Tierwelt der Nord- und Ostsee*. **1a**: 1–238,

Viets, K. (1936). Zoologische Ergebnisse einer Reise nach Bonaire, Curaçao und Aruba im Jahre 1930. No. 18. Halacariden aus Westindien. *Zoologische Jahrbücher für Systematik, Ökologie und Tiergeographie* **67**: 389–424.

Wells, F.E. and Walker, D.I. (1993). Introduction. *In* F.E. Wells, D.I. Walker, H. Kirkman and R. Lethbridge (eds), *The Marine Flora and Fauna of Rottnest Island, Western Australia*:1–10. Western Australian Museum, Perth.

Manuscript received 10 January 2003; accepted 4 April 2003

Records of the Western Australian Museum 22: 47–65 (2003).

Taxonomic status of the ricefield rat *Rattus argentiventer* (Robinson and Kloss, 1916) (Rodentia) from Thailand, Malaysia and Indonesia based on morphological variation

Ibnu Maryanto

Museum Zoologicum Bogoriense, R&D Centre For Biology,
Indonesia Institute of Sciences (LIPI). Jl. Raya Jakarta Bogor Km 46, Cibinong, Bogor, Indonesa
e-mail: ibnu_mar@yahoo.com; mzb@indo.net.id

Abstract – Comparison of cranial and external characters of 212 ricefield rats *Rattus argentiventer* (Robinson and Kloss 1916), by univariate and multivariate statistical analyses, was carried out on specimens from Thailand, Malaysia, and Indonesia (Sumatra, Kalimantan, Java, Bali, Lesser Sunda, Sulawesi and Irian Jaya). These comparisons indicate that ricefield rats from Thailand to Irian Jaya fall into four groups: a Java group (Thailand, Malaysia, Sumatra and Java), a Bali-Sulawesi group (Bali, Sulawesi, Lombok, Sumbawa, Adonara, Sangeang, Rinca, Flores, Lembata, Alor, Timor and Tanimbar Islands); a Sumba group (Sumba Island) and a Kalimantan group (Kalimantan Island). The specimen from Irian Jaya was placed in the Java group. The taxon from Kalimantan is described as a new subspecies, *R. a. kalimantan*.

The multiple regression analysis indicated that while skull, dentary, dental, and external characters of the ricefield rat do not exhibit sexual dimorphism, age or interactions between islands, sex and /or age does influence some characters.

Key words: Ricefield rat, *Rattus argentiventer*, morphological variation, Thailand, Malaysia, Indonesia.

INTRODUCTION

Recent reappraisal of the mammalian fauna of the Lesser Sunda and Sunda Islands has led to a dramatically different view of the biogeographic boundaries in the Oriental and Australian regions from the traditional ones based on Wallace's and Weber's lines (Kichener *et al.*, 1990; Kitchener and Maryanto, 1993; Kitchener *et al.*, 1995). The Indonesian archipelago presents unique opportunities to study morphological variation. Comprehensive re-evaluation of morphology in many cases resulted in the discovery of new species and subspecies. In Indonesia such re-evaluation has been conducted, for example, in bats, rodents and primates (Kitchener and Maryanto, 1993; Maryanto *et al.*, 1997; Maryanto and Kitchener, 2000).

The ricefield rat, *Rattus argentiventer*, a rodent species found in ricefields, is often a major pest. It is distributed through Thailand, Vietnam, Cambodia, Laos, Malaysia, Sumatra, Java, Kalimantan, Sulawesi, the Philippines, Lesser Sunda, and has been introduced to New Guinea (van Strien, 1986; Flannery, 1990; Suyanto *et al.*, 1999). There are indications that *R. argentiventer* has different behaviors in different locations (Maryanto, 1991). Recent authors recognized one species (Musser, 1977; van Strein, 1986), however Kitchener and Suyanto (1996) argued that a detailed examination of morphological variation between island populations is needed to resolve the taxonomic situation of widespread species such as the ricefield rat, especially in the Indo-Australian region.

A number of recent authors have discussed the taxonomic status of the ricefield rat. Prior to Musser's classification of species limits in Asian *Rattus*, most authors treated *R. argentiventer* as a subspecies of *Rattus rattus* (Olerman, 1951; Schwarz and Schwarz, 1967). Musser (1972) initially treated specimens of *R. argentiventer* from Bali, Lombok, Sumbawa, Flores and Timor as a subspecies of *R. rattus*, classifying them as *Rattus rattus bali*. He further considered that *R. r. saturnus* from Sumba Island was synonymous with *R. r. bali*. Specimens from Java were first described as *R. r. brevicaudatus* (Horst and Raadt, 1918) however Chasen (1940) considered this as a synonym of *R. r. argentiventer*. Specimens from Sulawesi described as *R. pesticulus* Thomas, 1921 were referred by Musser (1977) to *R. argentiventer*. Kitchener *et al* (1990) referred specimens from Lombok to *R. a. bali*.

This paper reports on a taxonomic reappraisal of *R. argentiventer*, as defined above, from Thailand, Malaysia, and Indonesia, based on an examination of morphological variation. Specimens from

mainland Southeast Asia north of the Isthmus of Kra and from the Phillipine islands have not been examined as part of this study.

MATERIALS AND METHODS

A total of 212 adult specimens (see Appendix 1) were studied. The specimens were collected from Thailand, Malaysia, Sumatra, Kalimantan, Java, Sulawesi, Bali, Lombok, Sumbawa, Sangeang, Flores, Adonara, Lembata, Alor, Sumba, Timor, Tanimbar, and from Irian Jaya (Figure 1). All specimens studied are in the collection of Museum Zoologicum Bogoriense (MZB), the Western Australian Museum (WAM) and the Raffles Museum, Zoological Reference Collection, Singapore (ZRC). A specimen was judged to be adult if both the basioccipital/basisphenoid and basisphenoid/presphenoid sutures were fused. Twenty-five measurements of skull, dental and dentary characters and four external characters were measured with calipers to 0.01 mm. The skull characters used were: BB, bulla breadth; BH, bulla height; BL, bulla length; BOZP, breadth of zygomatic plate; BS, braincase breadth; CBL, condillo basal length; GSL, greatest skull length; HB, braincase height; IFB, incisive foramen breadth; IL, incisive foramen length; IO, interorbital breadth; LOD, length of diastema; LOP, length of palatal; M^1W, upper molar 1 width; M^1M^1, upper molar 1 to molar 1; M^2M^2, upper molar 2 to molar 2.; M^3M^3, upper molar 3 to molar 3; MSF, mesopterygoid fossa width; NB, nasal width; NL, nasal length; DL, dentary length; POW, post orbital width; RAP, ramus angular process; TR, upper tooth row; ZB, zygomatic width. The external characters were HBL, head and body length; TL, tail length; E, ear length and HF, hind foot length. The complete character measurements are shown in Figure 2. The pelage descriptions follow the color terminology of Konerup and Wanscher (1983).

The statistical analyses were run in two steps, univariate analysis and multivariate analysis, as described in Maryanto and Sinaga (1998). Sexes were analyzed separately, as were the skull and external characters. Discriminant Function Analysis (DFA) was initially run for all characters and with all islands as separate groups for island groups. Islands with fewer than four specimens were treated as unallocated island groups. The DFA was then run for a subset of five or more skull characters, based on the criteria of minimized Wilk's lambda to select the best discriminating variables results obtained with the reduced character set were very similar to those based on all characters (Kitchener *et al.* 1993)

RESULTS AND DISCUSSION

Univariate statistics

Mean, standard deviation, minimum and maximum values and sample size are presented in Table 1. These suggest that, except for IFB, MSF,

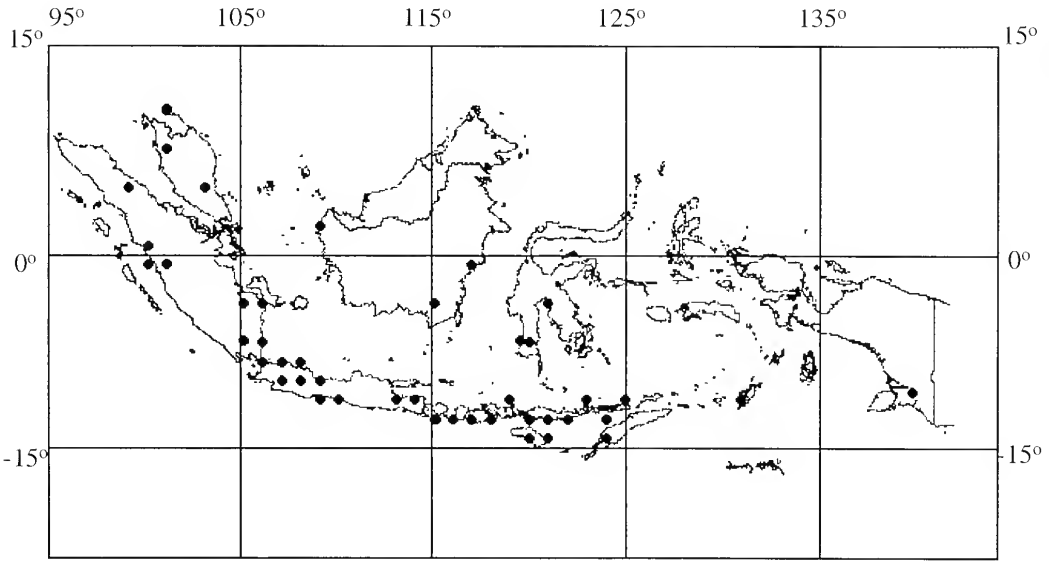


Figure 1 Localities of *Rattus argentiventer* specimens used in this study.

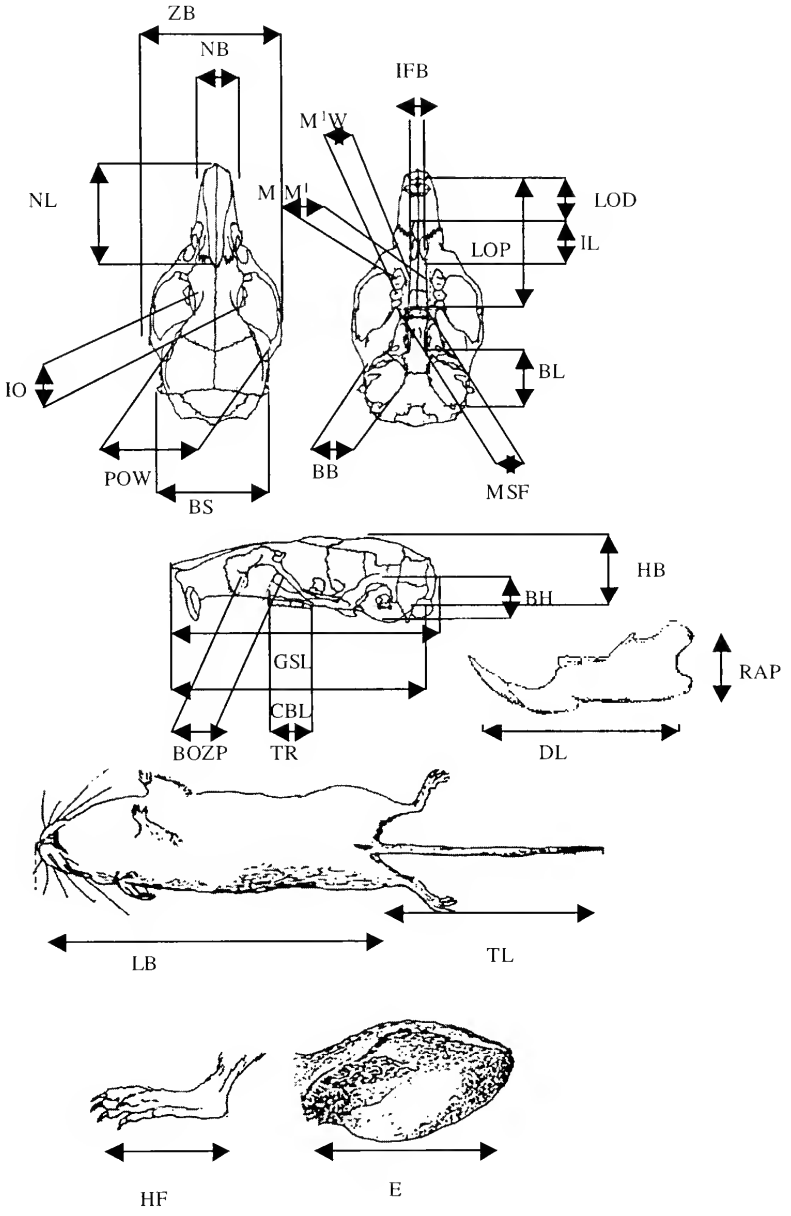


Figure 2 Sketch of the skull, dentary and external character measurements.

M^2M^2 and M^3M^3, all skull characters in males were slightly larger than in females. Furthermore, the averages of males and females from each group showed that the characters showing sexual differences differed in different groups. For example: The characters in males from Java were slightly larger than in females; nearly all characters in males from the Bali-Sulawesi group were larger than in females, except for IO, MSF, and M^1M^1-M^3M^3. Furthermore nearly all characters in males from Sumba were smaller than in females except for GSL, NB, and IFB; and lastly nearly all characters in males from Kalimantan were smaller than in females except for E, HF, MSF, BH, and M^1W (Table 1)

Multiple regression

Multiple regression analysis was employed to

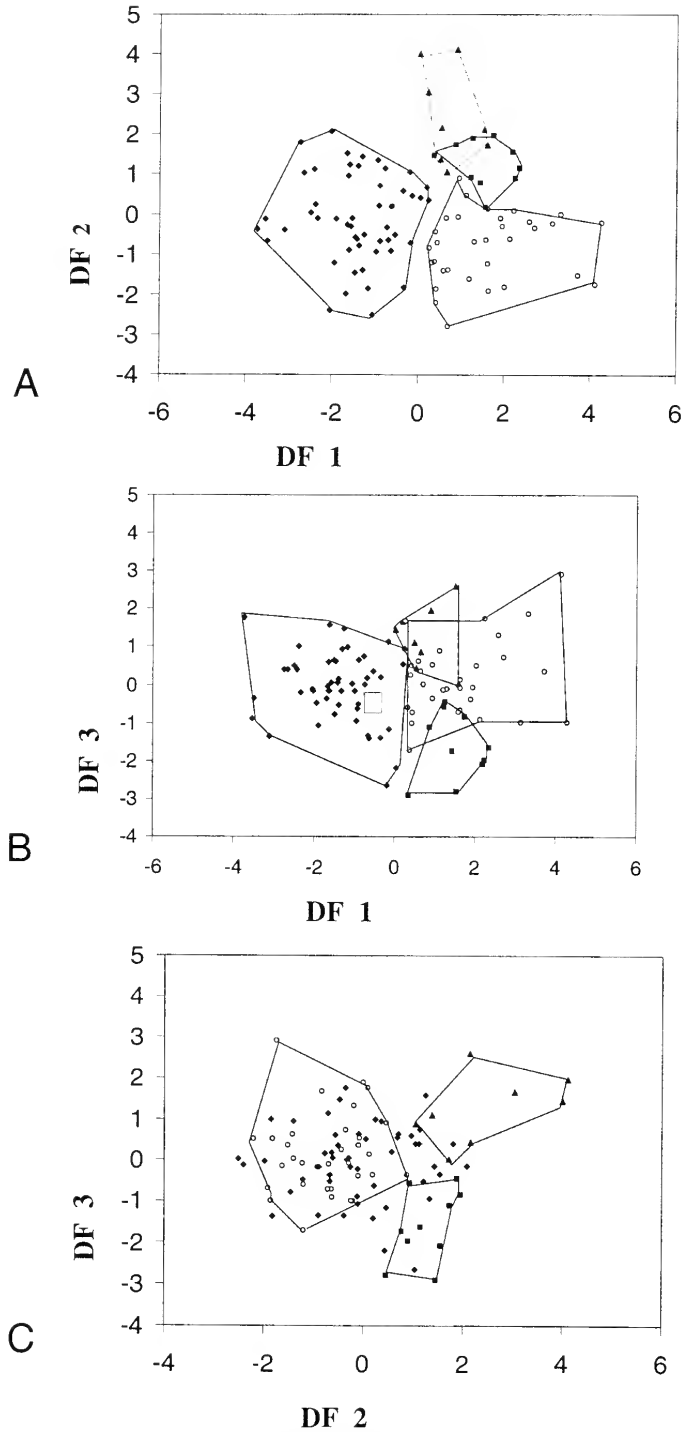


Figure 3 Plot of the female Canonical variate on the following island group populations; ♦ Java group (Thailand, Malaysia, Sumatra, and Java); ■ Kalimantan group (Kalimantan Island); ○ Bali group (Bali, Lombok, Sumbawa, Sangeang, Komodo, Flores, Adonara, Lembata, Alor, Timor and Tanimbar) and ✠ Sumba group (Sumba Island). A. Discriminant Function (DF) 1 vs. Discriminant Function 2 . B. Discriminant Function 1 vs. Discriminant Function 3 and C. Function 2 vs. Function 3.

Table 1 Male and female measurements of the skull, dentary and external characters (in mm).

Group	SEX		LB	TL	E	HF	GSL	ZB	HB	NL	NB	RAP
Java	Male	N	39	43	43	43	52	53	53	52	53	51
		Mean	182.82	168.19	20.05	34.72	41.02	19.74	11.76	14.48	4.41	13.01
		Std. Deviation	16.99	13.13	2.09	2.75	1.66	0.88	0.63	0.99	0.25	0.96
		Minimum	154.00	120.00	16.00	27.00	37.50	17.80	10.80	12.30	4.00	11.30
		Maximum	240.00	192.00	28.00	39.00	44.50	21.40	15.00	16.80	5.20	16.90
	Female	N	39	43	43	43	52	53	53	52	53	53
		Mean	172.38	155.07	19.34	33.33	39.79	19.53	11.59	14.01	4.33	12.67
		Std. Deviation	10.56	15.95	1.68	3.04	1.48	0.74	0.38	0.79	0.30	0.79
		Minimum	147.00	119.00	16.00	29.00	37.20	18.00	10.80	12.30	3.80	11.30
		Maximum	199.00	190.00	23.00	43.00	44.00	21.50	12.40	15.40	5.00	14.90
	Total	N	78	86	86	86	104	106	106	104	106	104
		Mean	177.60	161.63	19.69	34.02	40.40	19.64	11.68	14.24	4.37	12.84
		Std. Deviation	15.00	15.95	1.92	2.96	1.68	0.82	0.53	0.92	0.28	0.89
		Minimum	147.00	119.00	16.00	27.00	37.20	17.80	10.80	12.30	3.80	11.30
		Maximum	240.00	192.00	28.00	43.00	44.50	21.50	15.00	16.80	5.20	16.90
Sumba	Male	N	2	2	2	2	5	6	6	6	6	5
		Mean	152.00	151.50	18.00	32.50	41.76	19.51	11.64	15.03	4.99	12.05
		Std. Deviation	25.46	27.58	1.41	0.00	3.91	1.43	0.37	2.02	0.45	1.13
		Minimum	134.00	132.00	17.00	32.50	37.60	18.20	11.30	12.70	4.70	10.90
		Maximum	170.00	171.00	19.00	32.50	46.70	21.90	12.20	18.40	5.70	13.90
	Female	N	8	7	8	8	9	9	9	9	9	8
		Mean	180.81	168.43	21.06	34.00	41.68	20.39	12.22	15.11	4.83	13.40
		Std. Deviation	20.40	20.39	2.21	1.77	2.80	1.21	0.74	1.32	0.20	1.28
		Minimum	148.00	145.00	17.00	31.00	38.80	18.40	11.00	13.70	4.50	11.60
		Maximum	200.00	191.00	24.00	36.00	47.00	22.00	13.10	17.90	5.10	15.20
	Total	N	10	9	10	10	14	15	15	15	15	13
		Mean	175.05	164.67	20.45	33.70	41.71	20.04	11.99	15.08	4.89	12.88
		Std. Deviation	23.31	21.51	2.39	1.69	3.09	1.33	0.67	1.57	0.32	1.36
		Minimum	134.00	132.00	17.00	31.00	37.60	18.20	11.00	12.70	4.50	10.90
		Maximum	200.00	191.00	24.00	36.00	47.00	22.00	13.10	18.40	5.70	15.20
Bali	Male	N	21	21	20	20	36	35	35	35	36	34
		Mean	175.98	170.60	20.40	34.13	41.44	19.83	11.88	14.93	4.79	13.05
		Std. Deviation	12.57	13.24	1.70	2.17	2.70	1.30	0.69	1.27	0.45	2.07
		Minimum	157.00	144.00	17.00	29.00	36.60	17.10	10.50	12.20	4.00	10.70
		Maximum	213.00	201.00	23.00	37.00	46.50	22.70	13.50	17.50	5.90	22.50
	Female	N	22	22	22	22	37	37	36	37	37	36
		Mean	173.84	161.77	20.80	33.82	40.73	19.76	11.78	14.58	4.68	12.79
		Std. Deviation	14.12	17.51	1.84	2.14	2.27	1.42	0.64	1.00	0.44	2.01
		Minimum	145.00	120.00	17.00	30.50	36.50	17.30	10.50	12.40	4.00	10.50
		Maximum	201.00	194.00	24.00	39.00	45.60	23.20	13.20	16.70	5.60	22.70
	Total	N	43	43	42	42	73	72	71	72	73	70
		Mean	174.88	166.08	20.61	33.96	41.08	19.79	11.83	14.75	4.74	12.92
		Std. Deviation	13.27	16.02	1.76	2.13	2.50	1.35	0.66	1.15	0.44	2.03
		Minimum	145.00	120.00	17.00	29.00	36.50	17.10	10.50	12.20	4.00	10.50
		Maximum	213.00	201.00	24.00	39.00	46.50	23.20	13.50	17.50	5.90	22.70
Kalimantan	Male	N	5	5	5	5	5	5	5	5	5	5
		Mean	167.50	148.10	20.30	35.00	40.17	19.11	11.60	13.86	4.87	12.85
		Std. Deviation	18.43	10.85	0.84	2.83	1.68	1.04	0.35	1.06	0.35	0.86
		Minimum	139.50	135.50	19.00	32.00	38.10	18.20	11.30	12.30	4.60	12.00
		Maximum	187.00	163.00	21.00	38.00	42.50	20.70	12.10	15.10	5.40	14.10
	Female	N	11	11	10	11	12	12	12	12	12	12
		Mean	174.91	156.32	19.50	34.91	40.99	19.90	11.78	14.67	4.90	13.20
		Std. Deviation	14.17	11.09	1.18	2.59	1.52	0.76	0.42	0.76	0.24	0.62
		Minimum	150.00	136.00	17.00	30.00	38.90	18.70	10.80	13.00	4.60	12.30
		Maximum	199.00	172.00	21.00	38.00	44.50	21.00	12.30	15.80	5.20	14.30
	Total	N	16	16	15	16	17	17	17	17	17	17
		Mean	172.59	153.75	19.77	34.94	40.75	19.67	11.73	14.43	4.89	13.09
		Std. Deviation	15.39	11.35	1.12	2.57	1.57	0.89	0.40	0.91	0.27	0.69
		Minimum	139.50	135.50	17.00	30.00	38.10	18.20	10.80	12.30	4.60	12.00
		Maximum	199.00	172.00	21.00	38.00	44.50	21.00	12.30	15.80	5.40	14.30

Table 1 (cont.)

Group	SEX		LB	TL	E	HF	GSL	ZB	HB	NL	NB	RAP
Average – All combined												
	Male	N	67	71	70	70	98	99	99	98	100	95
		Mean	178.61	167.01	20.11	34.51	41.17	19.73	11.79	14.64	4.60	12.97
		Std. Deviation	16.97	14.43	1.92	2.56	2.22	1.08	0.63	1.19	0.41	1.46
		Minimum	134.00	120.00	16.00	27.00	36.60	17.10	10.50	12.20	4.00	10.70
		Maximum	240.00	201.00	28.00	39.00	46.70	22.70	15.00	18.40	5.90	22.50
	Female	N	80	83	83	84	110	111	110	110	111	109
		Mean	173.98	158.14	19.91	33.73	40.39	19.71	11.72	14.36	4.55	12.82
		Std. Deviation	13.23	16.50	1.85	2.68	1.98	1.07	0.54	0.97	0.40	1.34
		Minimum	145.00	119.00	16.00	29.00	36.50	17.30	10.50	12.30	3.80	10.50
		Maximum	201.00	194.00	24.00	43.00	47.00	23.20	13.20	17.90	5.60	22.70
	Total	N	147	154	153	154	208	210	209	208	211	204
		Mean	176.09	162.23	20.00	34.08	40.75	19.72	11.75	14.49	4.57	12.89
		Std. Deviation	15.18	16.15	1.88	2.65	2.13	1.07	0.58	1.09	0.41	1.40
		Minimum	134.00	119.00	16.00	27.00	36.50	17.10	10.50	12.20	3.80	10.50
		Maximum	240.00	201.00	28.00	43.00	47.00	23.20	15.00	18.40	5.90	22.70

Group	SEX		DL	M^1W	M^1L	IO	BOZP	LOP	TR	IL	MSF	IFB
Java	Male	N	52	52	51	53	53	53	53	53	53	53
		Mean	22.80	2.10	3.19	5.71	4.87	19.14	7.00	7.68	2.36	2.59
		Std. Deviation	1.04	0.11	0.22	0.26	0.39	0.92	0.32	0.48	0.22	0.24
		Minimum	20.70	1.90	2.30	5.10	4.00	17.60	5.70	6.60	1.90	2.20
		Maximum	24.60	2.30	3.50	6.40	5.90	21.40	7.50	8.50	2.90	3.20
	Female	N	53	53	51	53	53	53	53	53	53	53
		Mean	22.47	2.08	3.20	5.55	4.87	18.89	6.87	7.44	2.36	2.55
		Std. Deviation	1.26	0.09	0.20	0.23	0.41	0.89	0.27	0.81	0.20	0.25
		Minimum	20.50	1.90	2.80	5.00	4.00	17.10	6.30	2.80	1.90	2.10
		Maximum	26.00	2.20	3.70	6.00	6.00	21.40	7.40	8.70	2.80	3.30
	Total	N	105	105	102	106	106	106	106	106	106	106
		Mean	22.63	2.09	3.19	5.63	4.87	19.01	6.94	7.56	2.36	2.57
		Std. Deviation	1.16	0.10	0.21	0.26	0.40	0.91	0.30	0.67	0.21	0.25
		Minimum	20.50	1.90	2.30	5.00	4.00	17.10	5.70	2.80	1.90	2.10
		Maximum	26.00	2.30	3.70	6.40	6.00	21.40	7.50	8.70	2.90	3.30
Sumba	Male	N	6	6	2	6	6	6	6	6	6	6
		Mean	23.11	2.19	3.21	5.70	4.71	19.23	7.07	7.83	2.43	2.60
		Std. Deviation	1.86	0.06	0.08	0.39	0.45	1.48	0.09	0.58	0.14	0.38
		Minimum	21.50	2.10	3.20	5.30	4.30	18.00	7.00	7.40	2.30	2.30
		Maximum	25.80	2.30	3.30	6.40	5.60	21.80	7.20	8.70	2.60	3.20
	Female	N	9	9	9	9	9	9	9	9	9	9
		Mean	23.78	2.23	3.36	5.79	4.89	20.29	7.37	8.00	2.59	2.52
		Std. Deviation	1.76	0.12	0.22	0.29	0.51	1.43	0.22	0.57	0.20	0.22
		Minimum	21.90	2.00	2.80	5.40	4.40	18.70	7.10	7.30	2.20	2.10
		Maximum	26.20	2.40	3.60	6.20	6.00	22.80	7.80	9.10	2.90	2.90
	Total	N	15	15	11	15	15	15	15	15	15	15
		Mean	23.51	2.21	3.33	5.75	4.82	19.86	7.25	7.93	2.53	2.55
		Std. Deviation	1.77	0.10	0.21	0.32	0.48	1.50	0.23	0.56	0.19	0.29
		Minimum	21.50	2.00	2.80	5.30	4.30	18.00	7.00	7.30	2.20	2.10
		Maximum	26.20	2.40	3.60	6.40	6.00	22.80	7.80	9.10	2.90	3.20
Bali	Male	N	36	36	23	36	36	34	36	36	35	34
		Mean	22.60	2.14	3.30	6.06	4.78	19.80	7.10	7.85	2.33	2.58
		Std. Deviation	2.32	0.16	0.25	0.29	0.45	1.61	0.38	0.80	0.24	0.26
		Minimum	13.40	1.70	2.80	5.60	3.70	17.00	6.40	6.60	1.90	2.20
		Maximum	27.10	2.40	3.80	6.80	5.70	24.00	7.80	9.70	2.90	3.00
	Female	N	37	37	20	37	37	37	37	37	37	37
		Mean	22.62	2.13	3.25	6.09	4.64	19.64	7.15	7.41	2.40	2.58
		Std. Deviation	2.37	0.13	0.25	0.40	0.46	1.36	0.37	0.63	0.30	0.28
		Minimum	12.50	1.70	2.80	5.30	3.70	17.60	6.40	6.00	1.90	2.20
		Maximum	26.60	2.40	3.80	6.90	5.70	23.20	8.00	9.50	3.10	3.20
	Total	N	73	73	43	73	73	71	73	73	72	71
		Mean	22.61	2.14	3.27	6.07	4.71	19.72	7.13	7.63	2.36	2.58
		Std. Deviation	2.33	0.14	0.25	0.35	0.46	1.48	0.37	0.74	0.28	0.27
		Minimum	12.50	1.70	2.80	5.30	3.70	17.00	6.40	6.00	1.90	2.20
		Maximum	27.10	2.40	3.80	6.90	5.70	24.00	8.00	9.70	3.10	3.20

Group	SEX		DL	M¹W	M¹L	IO	BOZP	LOP	TR	IL	MSF	IFB
Kalimantan	Male	N	5	5	1	5	5	5	5	5	5	5
		Mean	22.75	2.20	3.23	5.61	4.61	19.41	6.94	7.45	2.35	2.47
		Std. Deviation	0.76	0.08	.	0.20	0.33	1.00	0.10	0.45	0.12	0.28
		Minimum	22.10	2.10	3.20	5.40	4.20	18.30	6.80	6.80	2.30	2.10
		Maximum	24.00	2.30	3.20	5.80	5.00	21.00	7.00	8.00	2.60	2.90
	Female	N	12	12	4	12	12	12	12	12	12	12
		Mean	23.54	2.19	3.28	5.85	4.90	19.68	7.08	7.48	2.29	2.59
		Std. Deviation	1.04	0.10	0.12	0.20	0.33	0.75	0.18	0.44	0.25	0.21
		Minimum	22.10	2.00	3.10	5.60	4.20	18.80	6.80	6.60	2.00	2.20
		Maximum	25.60	2.30	3.40	6.20	5.40	21.20	7.50	8.00	2.90	3.00
	Total	N	17	17	5	17	17	17	17	17	17	17
		Mean	23.31	2.19	3.27	5.78	4.81	19.60	7.04	7.47	2.31	2.56
		Std. Deviation	1.02	0.10	0.11	0.22	0.35	0.81	0.17	0.43	0.22	0.23
		Minimum	22.10	2.00	3.10	5.40	4.20	18.30	6.80	6.60	2.00	2.10
		Maximum	25.60	2.30	3.40	6.20	5.40	21.20	7.50	8.00	2.90	3.00
Average – All combined												
	Male	N	99	99	77	100	100	98	100	100	99	98
		Mean	22.74	2.12	3.22	5.83	4.82	19.39	7.04	7.74	2.35	2.58
		Std. Deviation	1.64	0.13	0.23	0.32	0.41	1.26	0.33	0.62	0.22	0.26
		Minimum	13.40	1.70	2.30	5.10	3.70	17.00	5.70	6.60	1.90	2.10
		Maximum	27.10	2.40	3.80	6.80	5.90	24.00	7.80	9.70	2.90	3.20
	Female	N	111	111	84	111	111	111	111	111	111	111
		Mean	22.74	2.12	3.23	5.78	4.80	19.34	7.03	7.48	2.38	2.56
		Std. Deviation	1.77	0.12	0.21	0.38	0.44	1.18	0.33	0.71	0.25	0.25
		Minimum	12.50	1.70	2.80	5.00	3.70	17.10	6.30	2.80	1.90	2.10
		Maximum	26.60	2.40	3.80	6.90	6.00	23.20	8.00	9.50	3.10	3.30
	Total	N	210	210	161	211	211	209	211	211	210	209
		Mean	22.74	2.12	3.23	5.80	4.81	19.36	7.03	7.60	2.37	2.57
		Std. Deviation	1.70	0.13	0.22	0.35	0.43	1.22	0.33	0.68	0.24	0.25
		Minimum	12.50	1.70	2.30	5.00	3.70	17.00	5.70	2.80	1.90	2.10
		Maximum	27.10	2.40	3.80	6.90	6.00	24.00	8.00	9.70	3.10	3.30

Group	SEX		BL	BH	BB	LOD	CBL	M^1M^1	M^2M^2	M^3M^3	BS	POW
Java	Male	N	53	53	53	53	51	51	50	50	51	51
		Mean	7.55	7.07	4.19	11.85	40.24	3.93	4.31	4.74	15.74	16.34
		Std. Deviation	0.38	0.30	0.33	0.72	2.69	0.35	0.37	0.35	0.57	0.54
		Minimum	6.50	6.20	3.50	9.90	26.30	3.14	3.50	4.03	14.58	15.27
		Maximum	8.30	7.60	5.30	13.00	44.60	4.58	5.04	5.62	16.97	17.42
	Female	N	53	52	53	53	52	53	53	53	53	53
		Mean	7.38	6.92	4.10	11.52	39.22	3.85	4.17	4.68	15.53	16.26
		Std. Deviation	0.33	0.24	0.27	0.56	1.45	0.42	0.41	0.39	0.61	0.62
		Minimum	6.80	6.40	3.60	9.90	36.80	2.98	3.41	3.97	13.71	14.89
		Maximum	8.10	7.40	4.80	12.80	43.00	4.78	5.34	5.73	16.89	17.92
	Total	N	106	105	106	106	103	104	103	103	104	104
		Mean	7.46	6.99	4.15	11.68	39.72	3.89	4.24	4.71	15.64	16.30
		Std. Deviation	0.36	0.28	0.30	0.66	2.21	0.39	0.39	0.37	0.60	0.58
		Minimum	6.50	6.20	3.50	9.90	26.30	2.98	3.41	3.97	13.71	14.89
		Maximum	8.30	7.60	5.30	13.00	44.60	4.78	5.34	5.73	16.97	17.92
Sumba	Male	N	6	6	6	6	6	6	6	6	6	6
		Mean	7.71	7.21	4.41	11.79	41.07	3.61	3.93	4.35	16.14	16.33
		Std. Deviation	0.52	0.39	0.49	1.17	3.67	0.45	0.52	0.51	0.86	0.39
		Minimum	7.00	6.80	3.90	11.10	36.90	3.01	3.24	3.75	14.91	15.81
		Maximum	8.60	7.90	5.20	14.20	46.60	4.05	4.54	4.89	17.19	16.90
	Female	N	9	9	9	9	9	9	8	8	9	9
		Mean	8.08	7.48	4.48	12.65	41.42	4.02	4.44	4.86	16.52	16.79
		Std. Deviation	0.68	0.41	0.21	1.00	3.30	0.49	0.59	0.57	0.83	0.63
		Minimum	7.30	6.90	4.00	11.50	37.70	3.27	3.39	3.83	15.53	15.98
		Maximum	9.00	8.00	4.80	14.10	47.50	4.68	5.24	5.56	18.18	17.71
	Total	N	15	15	15	15	15	15	14	14	15	15
		Mean	7.93	7.37	4.45	12.31	41.28	3.86	4.22	4.64	16.37	16.61
		Std. Deviation	0.63	0.41	0.34	1.12	3.33	0.50	0.60	0.59	0.83	0.58
		Minimum	7.00	6.80	3.90	11.10	36.90	3.01	3.24	3.75	14.91	15.81
		Maximum	9.00	8.00	5.20	14.20	47.50	4.68	5.24	5.56	18.18	17.71

Table 1 (cont.)

Group	SEX		BL	BH	BB	LOD	CBL	M^1M^1	M^2M^2	M^3M^3	BS	POW
Bali	Male	N	35	35	35	36	34	29	29	29	31	31
		Mean	7.49	7.00	4.19	12.14	40.67	3.92	4.29	4.73	15.98	16.67
		Std. Deviation	0.39	0.36	0.28	1.23	3.39	0.45	0.46	0.57	0.69	0.67
		Minimum	6.70	6.10	3.70	10.10	28.10	3.06	3.53	3.82	14.53	15.36
		Maximum	8.40	7.60	4.70	15.40	46.10	4.70	5.20	5.64	17.21	18.90
	Female	N	37	37	37	37	37	35	35	35	35	34
		Mean	7.43	6.95	4.14	11.80	40.13	3.97	4.47	4.97	15.70	16.52
		Std. Deviation	0.43	0.33	0.26	1.05	2.42	0.53	0.60	0.58	0.84	0.59
		Minimum	6.40	6.10	3.70	9.50	35.60	3.10	3.39	4.11	14.09	15.44
		Maximum	8.30	7.60	4.60	15.00	45.30	5.01	5.85	6.15	17.32	17.67
	Total	N	72	72	72	73	71	64	64	64	66	65
		Mean	7.46	6.97	4.17	11.97	40.39	3.95	4.39	4.86	15.83	16.59
		Std. Deviation	0.41	0.34	0.27	1.15	2.92	0.49	0.54	0.58	0.78	0.63
		Minimum	6.40	6.10	3.70	9.50	28.10	3.06	3.39	3.82	14.09	15.36
		Maximum	8.40	7.60	4.70	15.40	46.10	5.01	5.85	6.15	17.32	18.90
Kalimantan	Male	N	5	5	5	5	5	5	5	5	5	5
		Mean	7.57	7.02	4.27	11.64	39.39	3.97	4.22	4.73	16.34	15.92
		Std. Deviation	0.32	0.25	0.40	0.45	1.82	0.22	0.19	0.23	0.61	0.38
		Minimum	7.10	6.60	3.90	11.10	37.10	3.74	3.89	4.36	15.40	15.51
		Maximum	7.90	7.20	4.90	12.10	42.00	4.25	4.34	4.95	17.10	16.54
	Female	N	12	12	12	12	12	12	12	12	12	12
		Mean	7.57	7.01	4.34	11.89	40.41	3.99	4.30	4.74	16.34	16.12
		Std. Deviation	0.28	0.21	0.36	0.45	1.49	0.23	0.34	0.43	0.78	0.44
		Minimum	7.30	6.70	3.60	11.40	38.70	3.59	3.66	4.17	14.85	14.97
		Maximum	8.20	7.30	4.70	13.00	43.60	4.38	4.88	5.42	17.39	16.68
	Total	N	17	17	17	17	17	17	17	17	17	17
		Mean	7.57	7.01	4.32	11.82	40.11	3.98	4.27	4.74	16.34	16.06
		Std. Deviation	0.28	0.21	0.36	0.46	1.61	0.22	0.30	0.37	0.72	0.42
		Minimum	7.10	6.60	3.60	11.10	37.10	3.59	3.66	4.17	14.85	14.97
		Maximum	8.20	7.30	4.90	13.00	43.60	4.38	4.88	5.42	17.39	16.68
Average – All combined												
	Male	N	99	99	99	100	96	91	90	90	93	93
		Mean	7.54	7.05	4.21	11.94	40.40	3.91	4.27	4.71	15.88	16.43
		Std. Deviation	0.39	0.33	0.33	0.96	2.96	0.39	0.41	0.44	0.65	0.60
		Minimum	6.50	6.10	3.50	9.90	26.30	3.01	3.24	3.75	14.53	15.27
		Maximum	8.60	7.90	5.30	15.40	46.60	4.70	5.20	5.64	17.21	18.90
	Female	N	111	110	111	111	110	109	108	108	109	108
		Mean	7.47	6.98	4.17	11.74	39.83	3.91	4.30	4.79	15.76	16.37
		Std. Deviation	0.44	0.32	0.29	0.84	2.10	0.44	0.50	0.49	0.79	0.62
		Minimum	6.40	6.10	3.60	9.50	35.60	2.98	3.39	3.33	13.71	14.89
		Maximum	9.00	8.00	4.80	15.00	47.50	5.01	5.85	6.15	18.18	17.92
	Total	N	210	209	210	211	206	200	198	198	202	201
		Mean	7.50	7.02	4.19	11.84	40.10	3.91	4.29	4.76	15.81	16.40
		Std. Deviation	0.41	0.32	0.31	0.90	2.55	0.42	0.46	0.47	0.73	0.61
		Minimum	6.40	6.10	3.50	9.50	26.30	2.98	3.24	3.75	13.71	14.89
		Maximum	9.00	8.00	5.30	15.40	47.50	5.01	5.85	6.15	18.18	18.90

determine the influences of sex, age, localities and the interactions between these factors. All localities were included in the analysis (Malaysia, Sumatra, Java, Kalimantan, Sulawesi, Bali, Lombok, Sumbawa, Sangeang, Flores, Sumba, Adonara, Lembata, Alor, Timor, Tanimbar and Irian Jaya). The results are presented in Table 2.

Sex

Sex by itself had no significant effect at $P<0.05$ on any individual character.

Age

Most variables showed a significant influence of individual age; exceptions were NB, TR, IL, MSF, BB, RAP, M^1W and M^1L ($P<0.05$).

Locality

A locality is generally an island, except that the mainland Southeast Asian population is treated as a single locality (Malaysia). The variables ZB, NB, IO, IFB, BH, M^1W, BS, LB, and TL, were significantly influenced by locality.

Table 2 Multiple regressions on sex, age, locality, and the interactions among these factors for *Rattus argentiventer* in skull, dentary and external characters. F values are presented for the main effects and interactions (2 way and 3 way). Significance levels are *) 0.05>p>0.01, **) 0.01>p>0.001 and ***) P<0.001. For explanation of character codes see Materials and Methods.

Dependent Variable	Locality	Sex	Age	Locality Vs Age	Locality Vs Sex	Age Vs Sex	3 way Interactions
LB	3.530*	1.798	7.911***	2.806*	3.080*	3.190*	0.119
TL	4.494**	0.078	5.403**	1.323	0.989	1.950	0.279
E	1.486	0.298	7.077***	2.403	1.216	0.839	0.079
HF	0.836	0.022	0.791	0.070	0.267	0.281	0.143
GSL	1.681	1.846	23.601***	1.798	0.450	1.326	1.771
ZB	3.029*	1.421	16.225***	3.047*	2.278	1.802	0.008
HB	2.308	0.935	8.773***	1.606	0.930	2.938	0.121
NL	1.231	0.162	18.706***	1.082	1.114	0.932	1.184
NB	4.542**	1.574	2.476	0.393	0.707	0.012	0.963
IO	15.608***	1.045	6.579**	0.803	2.731*	0.807	0.008
BOZP	1.421	0.150	5.526**	0.422	0.569	0.410	0.058
LOP	0.126	3.213	14.552***	2.138	3.840*	0.743	0.554
TR	2.496	0.094	0.074	0.312	0.277	0.646	0.915
IL	1.082	2.642	2.316	1.022	0.198	1.512	0.389
MSF	2.679	0.021	2.914	0.658	0.659	0.320	1.251
IFB	3.252*	0.113	6.514**	0.175	2.855*	0.926	1.274
BL	2.330	0.040	8.130***	1.763	0.862	0.158	2.198
BH	3.566*	2.856	4.190*	0.383	1.332	0.676	0.630
BB	1.765	1.317	1.732	1.152	0.171	0.480	1.200
LOD	0.335	0.784	14.566***	1.942	2.991*	0.033	0.728
RAP	0.392	1.141	2.550	3.719**	0.895	1.142	0.265
DL	2.126	0.003	9.316***	1.656	0.382	0.219	1.337
M^1W	2.804*	0.006	0.122	0.244	0.459	2.402	0.286
M^1L	0.806	0.063	0.355	0.383	0.538	0.477	1.092
CBL	2.421	0.925	27.527***	2.877*	0.619	1.545	1.539
M^1M^1	0.562	0.231	10.771***	0.980	0.446	0.272	0.346
M^2M^2	1.380	0.224	11.644***	2.231	1.494	0.382	0.209
M^3M^3	2.605	2.571	9.670***	2.664*	2.418	0.286	0.925
BS	3.395*	1.449	7.235***	0.715	0.108	1.018	1.628
POW	2.011	0.806	6.465**	0.851	1.569	0.731	0.036

Interaction

The variables ZB, CBL, M^3M^3, LB at P<0.05 and RAP at P>0.01 were significantly influenced by the interaction between locality and age. The characters IO, LOP, IFB, LOD and LB (P<0.05) were significantly influenced by the interaction between locality and sex. Except for head and body length (P<0.05) there was no significant influence between age and sex (P>0.05). No variable showed a significant interaction between all three factors.

Multivariate analysis

The regression analysis showed that age strongly influenced many of the skull, dental and dentary characters, either individually or through interactions with sex or locality. Consequently the multivariate analysis was based on fully adult specimens as judged from basicranial fusion.

Although there is little interaction between sexual dimorphism in *R. argentiventer*, a total of five characters (LB, IO, LOP, IFB and LOD) showed a significant difference between sex and locality. For this reason, discriminant function (canonical variate) analysis was performed separately for males and females.

Females

An initial DFA was run using skull, dental and dentary characters and all locations. Because the number of characters employed in this analysis exceeded the sample size of the smallest group (Sumba, N=9), the DFA was repeated using a reduced set of seven characters in order to avoid over fitting the data (Kitchener and Maryanto 1995). The seven characters were selected by minimizing Wilk's lambda on the first canonical variate. The DFA plot was based on seven characters similar to that based on the complete character set. The seven characters in the DFA were IO, BH, BOZP, BS, M^3M^3, NB and MSF. This analysis extracted three significant functions, which together accounted for 100% of the variation. Discriminant Functions (DF) 1, 2, and 3 accounted for 63.02%, 24.60%, and 12.38% of the variation between populations respectively (Table 3). Each of the functions was highly significant DF1 (X^2=200.411; df=21; P=0.00001), DF 2 (X^2=91.305; df=12; P=0.00001) and DF 3 (X^2=33.432; df=5; P=0.00001). Reclassification of cases resulted in a correct allocation of 95.3% to localities

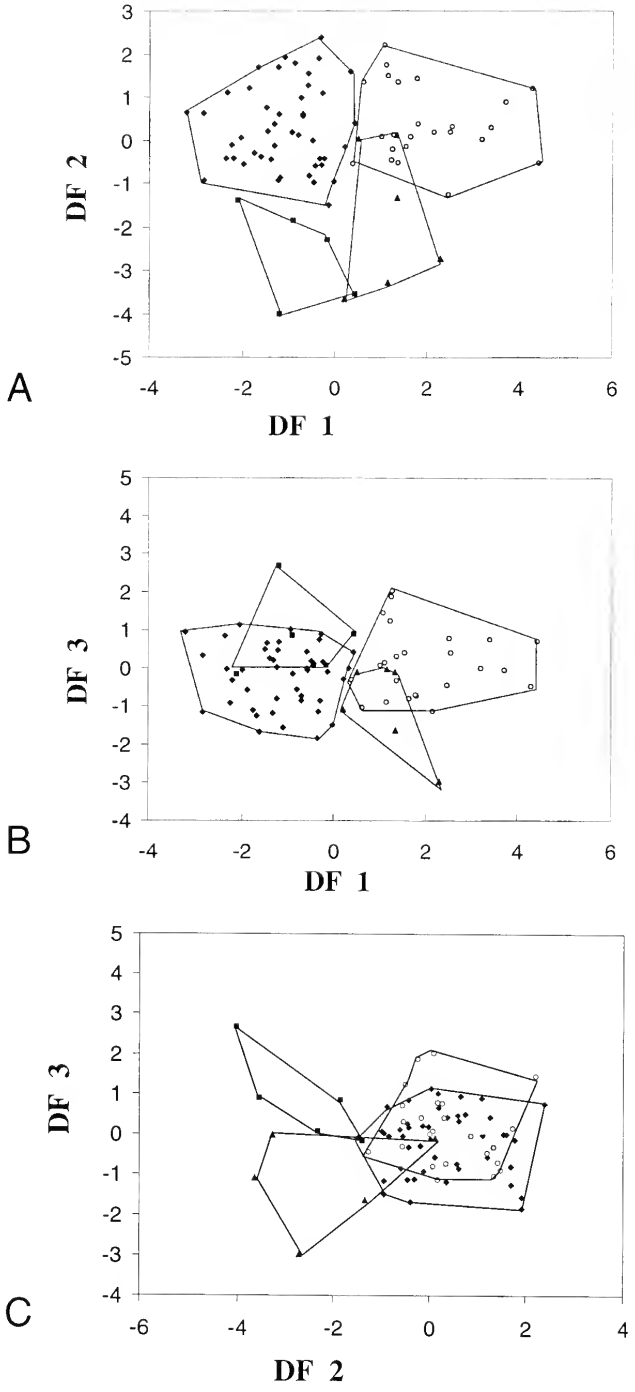


Figure 4 Plot of the male canonical variate on the following island group population 1; ♦ Java group (Thailand, Malaya, Sumatra, and Java); ■ Kalimantan group (Kalimantan Island); ○ Bali group (Bali, Lombok, Sumbawa, Sangeang, Komodo, Flores, Adonara, Lembata, Alor, Timor and Tanimbar) and ✠ Sumba group (Sumba Island). A. Discriminant Function (DF)1 vs. Discriminant Function 2. B. Discriminant Function 1 vs. Discriminant Function 3 and C. Discriminant Function 2 vs. Discriminant Function 3.

Three of the seven characters (BOZP, IO and NB) loaded heavily on DF1 (>0.5). These are evidently major characters, which display regional heterogeneity in populations of *R. argentiventer* in Indonesia. The DFA coefficients from this analysis are given in Table 3.

The configuration of DFA plots suggest that the ricefield rat contains four major morphological subpopulations (Figure 3). These are 1, a Java group (Thailand-Malaysia-Sumatra and Java); 2, Kalimantan; 3, a Bali-Sulawesi group (Bali, Lombok, Sumbawa, Sangeang, Komodo, Flores, Adonara, Lembata, Alor, Timor, Tanimbar and Sulawesi) and 4, Sumba. A bivariate plot between DF1 and DF2 shows that the Java group is separated from the Kalimantan, Bali-Sulawesi and Sumba groups on DF1 (Figure 3). A plot of DF2 against DF3 shows good separation of each of the Kalimantan, Sumba and Bali-Sulawesi groups. A single specimen from Irian Jaya, which was unallocated in the DFA falls within the Java group (Group 1). The Sulawesi population falls within group 3. A total of 94.2% of individuals in the Java group were correctly reclassified, with 5.7% (3 individuals) misclassified as Kalimantan. In the Bali-Sulawesi group, 94.3% of individuals were correctly reclassified with 2 individuals (2.9%) misclassified, one to each of the Java and Kalimantan groups. Finally, 100% (9 specimens and 10 specimens) of individuals from each of Sumba and Kalimantan were correctly reclassified.

Table 3 Standardized and unstandardized (in brackets) canonical variate function coefficients the derived from seven character analysis of female *Rattus argentiventer*

Variable	Function 1	Function 2	Function 3
IO	0.888 (3.784)	-0.472 (-2.014)	0.178 (0.760)
BH	0.066 (0.252)	0.547 (2.087)	0.782 (2.986)
BOZP	-0.794 (-1.953)	-0.218 (-0.537)	-0.289 (-0.712)
NB	0.639 (1.991)	0.437 (1.359)	-0.503 (-1.564)
M^3M^3	-0.306 (-0.702)	-0.781 (-1.791)	0.420 (0.963)
BS	0.389 (0.589)	0.870 (1.316)	-0.471 (-0.712)
MSF	-0.353 (-1.617)	0.133 (0.609)	0.675 (3.089)
Variation explained	63.02%,	24.60%,	12.38%
Constant	-25.078	-20.127	-15.232

Males

A DFA for males was run initially for the full set of 24 skull and dentary characters for all islands. However, because the sample size of the smallest groups (Kalimantan and Sumba) was 5 and 6, the analysis was repeated using a reduced set of five characters (BS, IO, NB, NL and M^1M^1) selected as for the female analysis.

The five characters selected by minimizing Wilk's lambda on the first canonical variate were IO, NB, M^1M^1, BS, and NL. Three of those variables were the same as those selected in the female analysis (IO, NL, BS); the others relate to similar components of the skull, namely the rostrum and the palate. The DFA plots produced with the reduced character set are similar to those based on the complete set of characters. This analysis extracted three significant functions, which together explained 100% of the variation. The DF 1: 67.93%, DF 2: 27.48%, and DF 3: 4.59% of each of these functions is highly significant (DF1: X^2=138.065; df=15; P=0.00001, DF 2: X^2=54.464; df=8; P=0.00001 and DF 3 X^2=9.553; df=3; P=0.022). The characters which loaded most heavily (>0.5) on DF1 were IO, M^1M^1 and NB.

The percentage of individuals correctly reclassified was 87.95%. In the Java group 91.5% of individuals were correctly reclassified with only 4.3% (2 individuals) misclassified to the Sumba group, and 4.3% to the Bali-Sulawesi group. A total of 66.7% of the individuals from Sumba were correctly reclassified with 33.3% (2 individuals) misclassified to the Bali-Sulawesi group. In the Bali-Sulawesi group, 88% of specimens were correctly reclassified with 4% (1 individual) and 8% (2 individuals) misclassified to the Java and Sumba groups respectively. Finally, 80% of individuals from Kalimantan were correctly reclassified with one individual misclassified to the Java group.

The Scatter plot between coefficient canonical 1 and 2 showed that the Java group was separated from the Sumba and Kalimantan groups (Figure 4). This bivariate plot also indicated that the Kalimantan individuals were separate from those in the Java, Bali-Sulawesi, and Sumba groups. Furthermore, individuals from Sumba were not clearly separated from those in the Bali-Sulawesi group.

SYSTEMATICS

Rattus argentiventer argentiventer Robinson and Kloss, 1916

Rattus rattus braivicaudatus Horst and Raadt, 1918

Rattus rattus chaseni Sody, 1941

Holotype

British Museum (Natural History) 19.11.5.89

Type locality

Pasir Ganting, west coast of Sumatra

Diagnosis

Robinson and Kloss (1918:55) described *R. a. argentiventer* as dorsally coarsely streaked, blackish and warm buff, grayer on the sides and limbs. The under parts are not clearly margined and are clad with fur having gray bases and white tips producing a general silvery effect, except on the

throat, which is white. A scarcely indicated buffy median stripe is present on the chest. The feet are parti-colored: tail brown throughout. This description serves equally for specimens from Thailand to Java. The skull of the typical form is distinguished from that of the other subspecies by the combination of a narrower interorbital region and narrower rostrum (Figure 5c).

Distribution

Thailand, Malaysia, Sumatra, and Java, possibly extending to Vietnam, Cambodia, Laos.

Rattus argentiventer kalimantanensis subsp. nov.

Holotype

Museum Zoologicum Bogoriense, MZB22419, adult male, weight 189 grams, carcass fixed in 70% ethanol, skull separated from body, collected by Ibnu Maryanto and M.H. Sinaga in March 2000.

Table 4 Male standard and unstandardized (in brackets) canonical variate function coefficients derived from the five character analysis of male *Rattus argentiventer*.

Variable	Function 1	Function 2	Function 3
BS	-0.309 (-0.524)	-0.781 (-1.318)	0.458 (0.774)
IO	0.848 (3.782)	0.742 (3.308)	0.289 (1.292)
NB	0.675 (2.198)	-0.948 (-3.086)	-0.029 (-0.097)
NL	0.339 (0.347)	0.731 (0.750)	-0.992 (-1.018)
M^1M^1	-0.680 (-2.100)	0.348 (1.075)	0.535 (1.650)
Variation explained	67.93%,	27.48%,	4.59%
Constant	-20.355	0.947	-10.794

Paratypes

See appendix for list of specimens examined

Type locality

Saka Gunung, Sei Kambat, Cerbon, Barito Kuala, South Kalimantan.

Diagnosis

Rattus argentiventer kalimantanensis females differ from *R. a. argentiventer* in averaging slightly larger in all skull dimensions except for BOZP. They differ from individuals in the Bali-Sulawesi group (*R. a. pesticulus*) in averaging slightly larger except dimensions for TR, DL, MSF, M^2M^2, M^3M^3, POW, IO, TL and E. They differ from individuals in the Sumba group (*R. a. saturnus*) by averaging slightly smaller except for NB, IO, BOZP, LOP, M1W, IFB, and HF.

Rattus argentiventer kalimantanensis males differ from *R. a. argentiventer* in averaging slightly smaller except for NB, LOP, M^1M^1, POW, BB, M^1W, BL, E, and HF. They differ from *R. a. saturnus* in averaging smaller except for RAP, M^1W, M^1M^1, M^2M^2, M^3M^3, BS, POW, LOP, GSL, LB, E, and HF. They differ from *R. a. pesticulus* in averaging slightly smaller except for NB, IO, M^1M^1, BS, BB, PL, M^1W, MSF, BL, BH, and HF.

Scatter plots of skull characters show that the interorbital breadth of male *R. a. kalimantanensis* is generally narrower relative to braincase breadth than *R. a. pesticulus* (Figure 5a). The nasal breadth females of *R. a. kalimantanensis* is generally larger relative to zigomatic breadth of *R. a. argentiventer* (Figure 5b)

Etymology

Named after the location on which the specimens were collected.

Pelage

Ventral fur with yellowish white tipping and base pastel gray to light gray; chest yellowish gray. Dorsum light brown on the tip and dark gray to purplish gray on the base, with sparse mixture of yellowish gray hairs. Forefeet grayish brown to yellowish brown, hindfeet grayish yellow to light blond.

Distribution

Widely distributed in Kalimantan (see Appendix for localities).

Rattus argentiventer saturnus Sody, 1941

Holotype

RMNH 9808 skin and skull collected by G. Stein

Type locality

Melolo, Sumba.

Diagnosis

Female *R. a. saturnus* from Sumba Island differ from *R. a. pesticulus* from Bali, Lombok, Sumbawa, Sangeang, Rinca, Komodo, Flores, Adonara, Timor, Alor, Tanimbar and Sulawesi in averaging slightly larger in nearly all skull characters except M^2M^2, M^3M^3, IO, and IFB. Males differ from *R. a. pesticulus* in averaging slightly larger except for GSL, NL, NB, MSF, IFB, BL, BH, BB, PL, M^1W, CBL, BS, MSF, IFB, BL, and BH.

Males differ from *R. a. argentiventer*, in averaging slightly larger in all skull characters except LOD, RAP, M^1M^1, M^2M^2, M^3M^3, ZB, HB, IO, and BOZP. Females differ from *R. a. argentiventer* by averaging slightly larger except for IFB.

Sody (1941) in describing *saturnus*, distinguished it only from *bali*, the taxon that applies to *R. argentiventer* from the Island of Bali. He noted that the differences between the two taxa were the length of tail relative to length of head and body and length of toothrows.

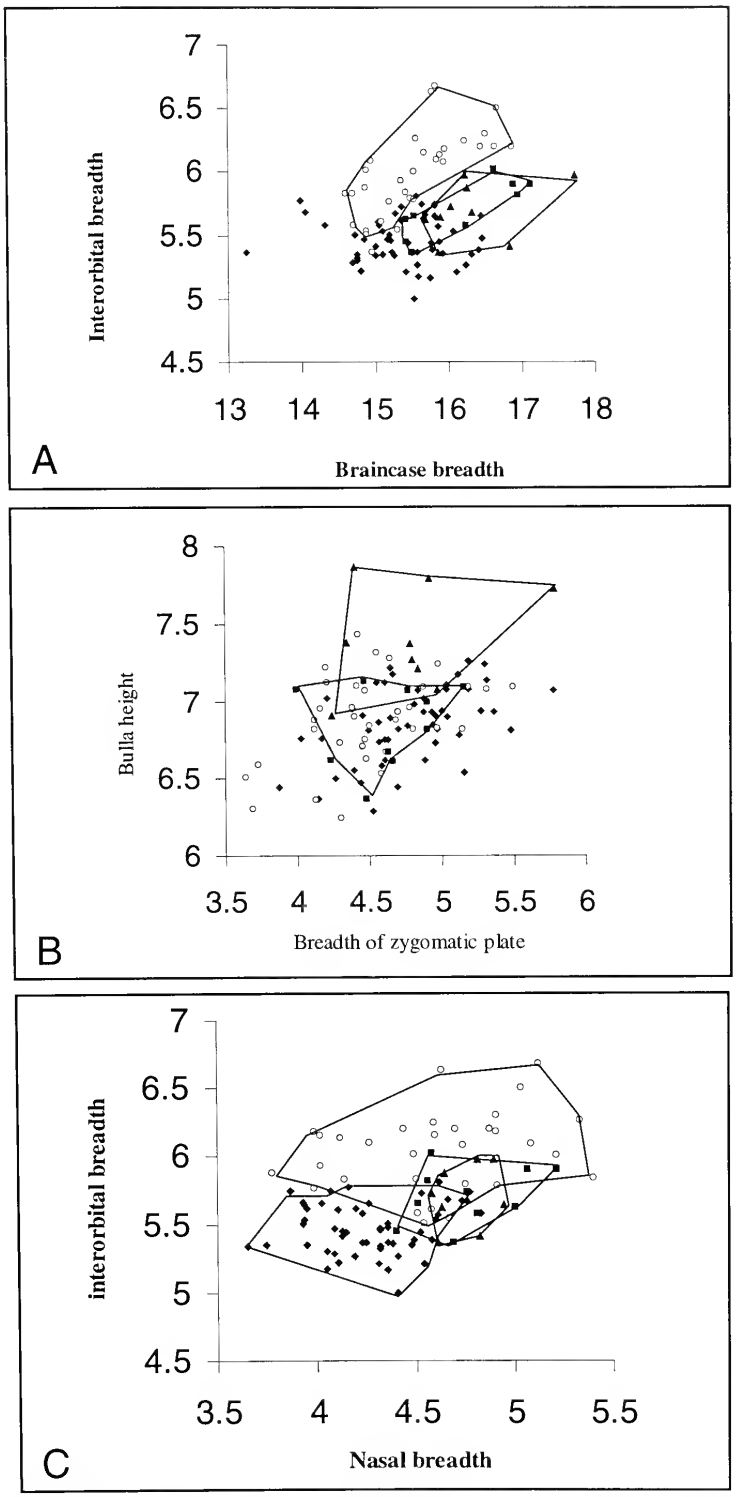


Figure 5 Bivariate plots of the female specimens. A. interorbital breadth against braincase breadth; B. Bulla height against breadth of zygomatic and C. interorbital breadth against nasal breadth. Groups of locality codes as for Figure 3.

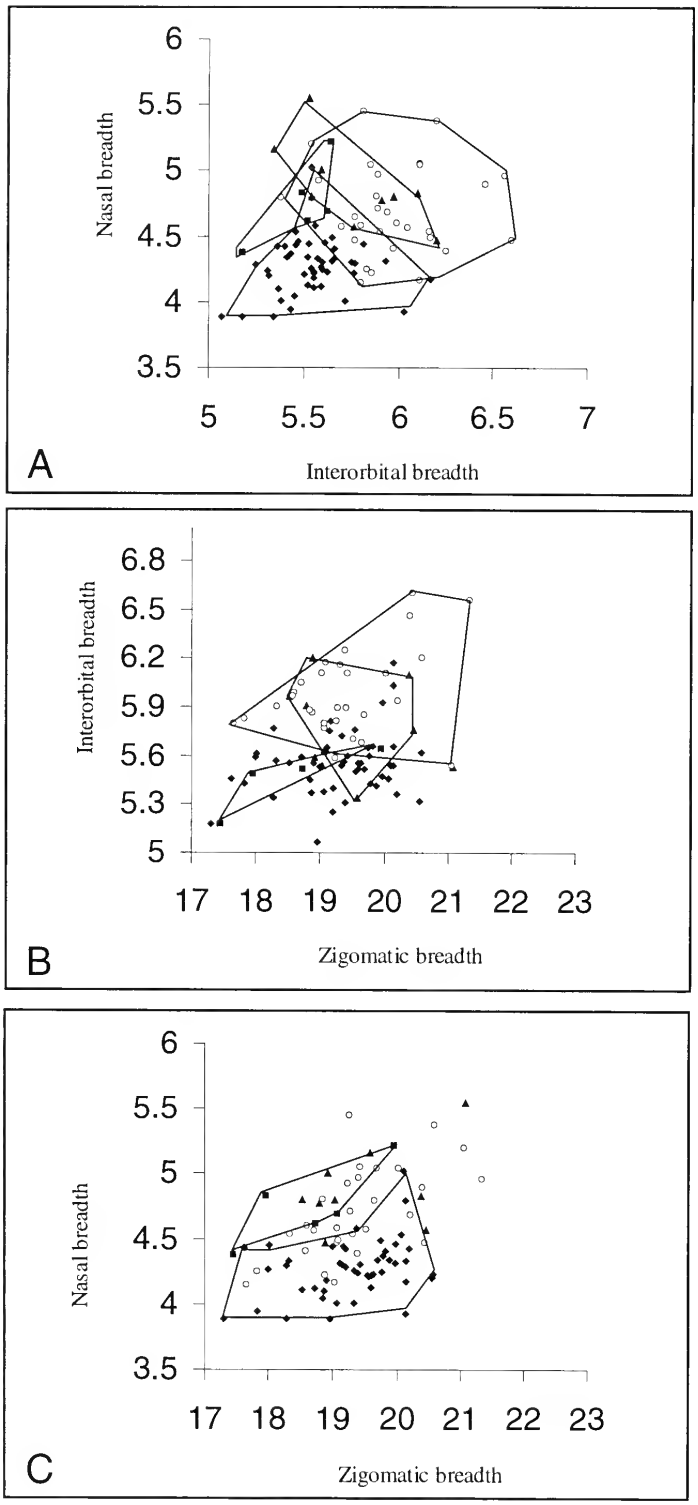


Figure 6 Bivariate plots of the male specimens. A. interorbital breadth against nasal breadth B. interorbital breadth against zygomatic breadth; C. Nasal breadth against zydomatic breadth. Locality group codes as for Figure 3.

Description

Musser (1972) described *R.a. saturnus* as having coarsely salt and peppered yellowish brown upper parts and silvery gray under parts as contrasted to the solid brown upper parts and creamy or buffy brown underparts of *R. rattus*. Juvenile and young adults have yellowish orange ear tufts that contrast conspicuously with the color of the head.

Distribution

Sumba Island

***Rattus argentiventer pesticulus* Thomas, 1921**

***Rattus rattus bali* Kloss, 1921**

***Rattus argentiventer bali* Kloss, 1921**

Holotype

Adult female B.M. skin and skull in BMNH no. 21.2.9.11

Type locality

Laboehan Anak and Klungkung, Bali (Cotypes)

Diagnosis

Female *R. a. pesticulus* differ from female *R. a. argentiventer* by averaging slightly larger except for BOZP, IL, LB, and HF. The males differ by averaging slightly larger except for BOZP, MSF, BL, BH, PL, M^2M^2, and M^3M^3.

Description

Thomas (1921) described *R. a. pesticulus* from the Sulawesi type specimen as fur thin and coarse, not definitely spinous. General color above dull reddish brown, sides rather grayer, under surface sharply defined white, the hairs on the throat with gray bases. Hand and feet white. Tail of medium length thinly haired, light brown, almost white basally. The color variation with Bali specimens that are described by Kloss (1921) as dorsally grizzled ochraceous tawny and brownish black, below creamy white often with traces of a median grey stripe. Forefeet brown, hind feet white, broadly brown mesially. Skulls robust with rather short broad rostrum, broad palatal foramina and large bullae.

Distribution

Bali, Lombok, Sumbawa, Sangeang, Komodo, Flores, Adonara, Lembata, Alor, Timor, Tanimbar and Sulawesi

DISCUSSION

Although Chasen and Kloss (1928) believed specimens of the ricefield rat from Kalimantan to be identical to typical *R. argentiventer* from Sumatra, the present analysis has shown that these populations are quite distinct on skull morphology. Differentiation on external characters is less pronounced with poor discrimination between these populations based on external measurements; typically less than 50% of individuals could be correctly classified. One external feature that does distinguish the population from the others is the more yellowish ventral surface due to an increased number of ventral hairs with yellow tips in Kalimantan specimens. This taxon is undescribed. At present it is best referred to as the "Kalimantan Population" of *R. argentiventer*. Musser (1973) argued that individuals from Sumba closely resemble those from Bali and allied these populations to those found further east on Lombok, Sumbawa, Komodo, Rinca, Flores and Timor. In the present analysis female specimens from Sumba are distinct from all other populations. In contrast, males from Sumba show overlap with other groups. I consider that *R. argentiventer* from Sumba are sufficiently distinct to warrant subspecies status as *R. a. saturnus* Sody, 1941.

Specimens from Sulawesi appear from this analysis to be referable to Bali, Lombok to Timor and the Tanimbar Islands group. Musser (1973) considered *R. argentiventer* to be recently introduced to Sulawesi and this is supported by my findings. Thomas (1921) described specimens from Sulawesi collected 1908 by Dr. Mohari from Manado as *Rattus pesticulus* In the same year he redescribed *Rattus pesticulus*. Musser (1973; 1977) considered *R. pesticulus* to be a junior synonym of *R. argentiventer*. Also in 1921 Kloss described *R. r. bali*. Laurie and Hill (1954) considered that *R. r. bali* was a synonym of *R. argentiventer* as did Musser (1973). The specimens included in this study from Lombok were referred to *R. argentiventer bali* by Kitchener *et al.* (1990). Since my analysis indicates that the Sulawesi population is indistinguishable from those from Bali, Lombok, Sumbawa-Timor and Tanimbar Islands then two names become available for this taxon: *R. bali* and *R. pesticulus*. Thomas described *Rattus pesticulus* twice, once in May 1921 (Thomas 1921a) and once in an undated volume of Treubia in 1921 (Thomas 1921b). In the same volume of Treubia, but with a later pagination, Kloss described *R. bali*. The earlier page number for *R. pesticulus* gives it nomenclatural priority over *R. bali*, thus fixing the subspecific name for the *R. argentiventer* rats of Bali, Lombok, Sumba, Timor and the Tanimbar Islands as *R. a. pesticulus* (Thomas, 1921).

Specimens from Java, Sumatra and Thailand could not be separated in this study. This supports the view that *R. a. brevcaudatus* (Horst & de Raadt) from Java and *R. a. chaseni* (Sody) from Malaysia are identical with typical *R. argentiventer*.

The single specimen from Tanah Merah, Irian Jaya fitted within the scatter of *R. a. argentiventer* rather than with the geographically closer R. *a. pesticulus*. This is quite possible since the port at Tanah Merah has been used by navigators and trading vessels for centuries as a safe anchorage (Flannery 1990).

A major limitation to examining the morphological differences between populations of *R. argentiventer* is the marked variation related to individual age. In the present study it was necessary to separate juveniles and subadults from mature animals and to exclude the younger individuals from the analysis. Furthermore it was necessary to analyse males separately from females. For these reasons, it has proved impossible to provide concise diagnoses for the various morphologically distinct subspecies of *R. argentiventer* I have recognised on morphometric grounds. Kitchener and Suyanto (1996) discussed a similar pattern of morphological variation for a range of mammal groups in Indonesia. They concluded that the geomorphological and climatic diversity within the Indonesian Archipelago has provided an ideal setting for complex evolutionary processes leading to morphological change. They further suggested that many of these morphological changes might be of relatively recent origin. This observation is particularly pertinent in the case of taxa such as *R. argentiventer*, which may have expanded its geographic range in parallel with the spread of rice agriculture over the last few thousand years. An analysis of genetic markers will be needed to fully elucidate some of these recent evolutionary events.

ACKNOWLEDGEMENTS

I am grateful to Mr. M.H. Sinaga, technician of Balitbang Zoologi-LIPI, Dr. R.A. How and Mr. Ron Johnstone from the Western Australian Museum, Dr. Kelvin Lim and C.M. Yang from the University of Singapore for assisting in the laboratory and fieldwork. I am also grateful to Dr. D.J. Kitchener from the Western Australian Museum, for funding fieldwork to the Lesser Sunda Islands, for his companionship in the field and for his comments on this manuscript. I am grateful also to Dr. Chris Watts from the South Australian Museum, for his comments on the manuscript. Finally I am grateful to the Nagao Foundation for supporting development of data from the Zoological Reference Collection, National University of Singapore and for supporting fieldwork in Sumatra and Kalimantan.

REFERENCES

Chasen, F.N and Kloss, C.B. (1928). On some Carnivora, Rodentia and Insectivora from Eastern Borneo. *Malayan Branch Royal Asiatic Society*. **6**: 38–48

Chasen, F.N. (1940). A Handlist of Malaysian Mammals. A systematic list of the mammals of the Malay Peninsula, Sumatra, Borneo. *Bulletin Raffles Museum* **15**: 1–209

Flannery, T. (1990). *Mammals of New Guinea*. The Australian Museum, Sydney.

Horst M.D. and de Raadt, O.L.E. (1918). De juiste namen voor de javaansche groote huisrat en de sawahrat. *Tijdschr vergelijk geneesk Dierz Leiden* **3**(4): 253–255.

Kitchener, D.J., Boeadi, Charlton, L. and Maharadatunkamsi. (1990). Mammals of Lombok Island, Nusa Tenggara, Indonesia: systematics and natural history. *Records of the Western Australian Museum, Supplement* **33**: 1–129.

Kitchener, D.J., How, R.A., Cooper, N.K. and Suyanto, A. (1992). *Hipposideros diadema* (Chiroptera, Hipposiderosidae) in the Lesser Sunda: taxonomy and geographic, morphological variation. *Records of the Western Australian Museum*. **16**: 1–60

Kitchener, D.J. and Maryanto, I. (1993). Taxonomic reappraisal of *Hipposideros larvatus* species complex (Chiroptera: Hipposideridae) in the Greater and Lesser Sunda Islands, Indonesia. *Records of the Western Australian Museum* **16**: 119–174

Kitchener, D.J., Cooper, N. and Maryanto, I. (1995). The *Myotis adversus* (Chiroptera, Vespertilionidae) species complex in Eastern Indonesia, Australia, Papua New Guinea and the Solomon Islands. *Records of the Western Australian Museum* **17**: 191–212

Kitchener, D.J. and Maryanto, I. (1995). A new species of *Melomys* (Rodentia, Muridae) from Yamdena Island, Tanimbar Group, Eastern Indonesia. *Records of the Western Australian Museum* **17**: 43–50

Kitchener, D.J. and Suyanto, A. (1996). Intraspecific morphological variation among island populations of small mammals in Southern Indonesia. *In*: Kitchener, D.J. and Suyanto, A. (eds) *Proceedings of the first International Conference on Eastern Indonesia-Australian Vertebrate Fauna*. Manado Nov 22-23, 1994: 7–13

Kitchener, D.J. and Maharadatunkamsi, (1996). Geographic variation in morphology of *Cynopterus nusatenggara* (Chiroptera, Pteropodidae) in southeastern Indonesia and descriptions of two new subspecies. *Mammalia* **60**(2): 255–276

Kloss, C.B. (1921). Some rats and mice of the Malay Archipelago. *Treubia* **2**(1): 115–124.

Kornerup, A. and J.H. Wanscher, (1978). *Methuen Handbook of Color*. 3rd edition. Methuen, 252 pp.

Laurie, E.M.O. and Hill, J.E. (1954). List of land mammals of New Guinea, Celebes and adjacent islands 1758–1952. *Trustees of the British Museum*, London. 4+175.

Maryanto, I. (1991). Burrow structure in relation to hoarding habit of *Rattus argentiventer* in two habitats (Miscellaneous notes). *Journal of the Bombay Natural History Society* **88** (3): 439.

Maryanto, I., Mansjoer, I., Sajuthi, D., and Suprijatna, J. (1997). Morphological variation of the silver leaf monkeys *Trachypithecus aurattus* (E. Geoffroy, 1812) and *Trachypithecus cristatus* (Raffles, 1821) from Thailand, Malaya and Indonesia. *Treubia* **31**: 113–131

Maryanto, I. and Sinaga, M.H. (1998). Variasi morfologi Maxomys surifer asal Sumatra, Kalimantan dan Jawa. *Berita Biologi* 5: 183–191

Musser G.G. (1972). Identities of taxa associated with *Rattus rattus* (Rodentia, Muridae) of Sumba Island, Indonesia. *Journal of Mammalolgy* **53** (4): 861–865.

Musser G.G. (1973). Zoogeographical significance of the ricefield rat *Rattus argentiventer* on Celebes and New Guinea and the identity of *Rattus pesticulus*. *American Museum Novittates* **2511**: 1–30.

Musser G.G. (1977). *Epimys benguetensis*, a composite, and one zoogeographic view of rat and mouse faunas in the Philipine and Celebes. *American Museum Novittates* **2624**: 1–15.

Olerman, J.R. (1951). *Checklist of Palaeartic and Indian Mammals, 1757–1946*. London, British Museum (Natural History).

Schwarz, E. and Schwarz H.K. (1967). A Monograph of *Rattus rattus* group. *Ann. Esc. Nac. Cien. Biol.*, Mexico. **14**: 79–178.

Robinson, H.C. and Kloss, C.B. (1918). Preliminary diagnoses of some new sp. and ssp. of mammals and birds obtained in Korinchi, W. Sumatra, 1914. *Journal of the Straits Branch Royal Asiatic Society* **73** (2): 269–278.

Robinson, H.C. and Kloss, C.B. (1918). Mammals of Korinchi. *Journal of the Federated Malay States Museums* **8**: 1–72.

Sody, H.J.V (1941). On a collection of rats from the Indo Malayan and Indo-Australian Regions (With descriptions of 43 new genera, species and subspecies). *Treubia* **18** (2): 255–325.

van Strien, N.J. (1986). *Abbreviated checklist of the mammals of the Australasian Archipelago. School of Enviromental Conservation Management*, Bogor. Indonesia. 91 pp

Suyanto, A., Yoneda, M., Maryanto, I., Maharadatunkamsi, and Sugarjito, J. (1998). *Checklist of the mammals of Indonesia. Scientific name and distribution area table in Indonesia including CITES, IUCN and Indonesia category for conservation*. LIPI-JICA. 34pp

Thomas, O. (1921). On a new genus and species of shrew and some new Muridae from the East-Indian archipelago. *Annals and Magazine of Natural History*. Series 9 **7**(39): 243–249.

Manuscript received 17 December 2001; accepted 11 November 2002

Appendix 1 List of locality, sex, number of specimens, latitude and longitude (ZRC = Zoological Reference Collection, Singapore; MZB = Museum Zoological Bogoriense, Bogor-Indonesia; WAM = Western Australian Museum, Perth Western Australia).

Malaysia and Thailand
Kualalumpur, Female, ZRC 2143, (3.08 N, 101.75 E)
Pahang, Female, ZRC 87140, 87341 (3.37 N, 102.83 E)
Perak, Female, ZRC 269/3, ZRC 3716, ZRC 4269, ZRC 4273, ZRC 6197 (4.87 N, 100.75 E)
Perak, Male, ZRC 580/1, ZRC 584/1, ZRC 909/2, ZRC 2044, ZRC 4268 (4.87 N, 100.75 E)
Bang-Penin-Siam, Female, ZRC 4274, ZRC 19073 (6.83 N, 101.25 E)
P.Sirih-Siam, Male, ZRC 4227.

Sumatra
Jabung Lampung, Male, MZB11480 (5.48 S, 105.67 E)
Kayu Agung, Female, MZB 12795 (3.40 S, 104.83 E)
Kp. Halaban, Painan, Male, MZB 4864, MZB 4870, MZB 4873 (1.35 S, 100.57 E)
Kp. Halaban, Painan, Female, MZB 4871 (1.35 S, 100.57 E)
Loboek Sikaping, Female, MZB 4862, MZB 4865, (0.13 N, 100.17 E)
Loeboek Sikaping, Male, MZB 4869, MZB 15345 (0.13 N, 100.17 E)
Memudjan, Padang, Female, MZB 4866, MZB 4868, (0.95 S, 100.35 E)
Padang, Male, MZB 15341, MZB 15347, MZB 15349 (0.95 S, 100.35 E).
Padang, Female, MZB 4872 (0.95 S, 100.35 E)
Mulyorejo, Way Abung, Female, MZB 13336, (4.83 S, 104.88 E)
Mulyorejo, Way Abung, Male, MZB 13431 (4.83 S, 104.88 E)
Pematangsiantar, Sumatra, Male, MZB 10459, MZB 10460 (2.95 N, 99.05 E)
Sindang Datar Lebuay, Pulau Panggung, S. Lampung Female, MZB 11245 (2.80 S, 105.95 E)
Wai Lima Lampung Male, MZB 337, MZB 361, (9.48 S, 104.52 E)

Java
Banyuwangi, Male, MZB 15348, (8.00 S, 114.08 E)
Bagusan W.Java, Female, MZB 3379, MZB 3381 (6.32 S, 106.83 E)
Bagusan W.Java, Male, MZB 3380, MZB 3382, MZB 3383, (6.32 S, 106.83 E)
Bajulmati, Male, ZRC 8680 (7.93 S, 114.42 E)
Bandung, Male, MZB 10211, (6.90 S, 107.60 E)
Bogor Male, MZB 4880, MZB 4881, MZB 4886, MZB 4889, MZB 4898, MZB 7027, MZB 7028 (6.58 S, 106.78 E)
Bogor Female, MZB 4887, MZB 4890, (6.58 S, 106.78 E)
Boyolali, Female, MZB 10205, MZB 10207, MZB 10208 (7.53 S, 110.33 E)
Boyolali, Male, MZB 10206, (7.53 S, 110.33 E)
Cawang Jakarta, Male, MZB 3342, MZB 3392 (6.25 S, 106.87 E)
Cawang Jakarta, Female, MZB 3439, MZB 8047, MZB 8054, MZB 8055 (6.25 S, 106.87 E)
Jakarta, Female, MZB 180, (6.10 S, 106.88 E)
Tj. Priok Jakarta, Male, MZB 3281 (6.10 S, 106.88 E)
Cirebon, Female, MZB 2145, MZB 2146 (6.73 S, 108.57 E)
Gandrungmangu, Cilacap, Male, MZB 13434 (7.53 S, 108.85 E)
Garut W.Java, Female, MZB 4897, (7.22 S, 107.90 E)
Kresek penameng W.Java, Female, MZB 12541 (6.10 S, 106.65 E)
Kresek penameng W.Java, Male, MZB 12542, (6.10 S, 106.65 E)
Malang Female, MZB 4885 (7.98 S, 112.62 E)
Palimanan Cirebon, Male, MZB 587 (6.73 S, 108.57 E)
Palimanan Cirebon, Female, MZB 588 (6.73 S, 108.57 E)
Pamanukan, Subang. Female, MZB 12361, MZB 12363, MZB 12367, MZB 12369, MZB 12561 (6.27 S, 107.82 E)
Pamanukan, Subang. Male, MZB 12364, MZB 12365 (6.27 S, 107.82 E)
Pandegglang, Female, MZB 4900, (6.30 S, 106.10 E)
Randudongkal, Pemalang, Female, MZB 12375, MZB 12376, MZB 12564, MZB 12365 (7.10 S, 109.32 E)
Randudongkal, Pemalang, Male, MZB 12377, MZB 12380, MZB 12383 MZB 12388, MZB 12389, MZB 12398, MZB 12563 (7.10 S, 109.32 E)
Serang, N. Banten, Male, MZB 4892, MZB 4893, MZB 4894, (6.08 S, 106.08 E)
Noesa Kambangan, Male, MZB 4903, MZB 5873 (7.75 S, 108.92 E)
Noesa Kambangan, Female, MZB 4904, MZB 4905, MZB 4908, MZB 4909, MZB 8444 (7.75 S, 108.92 E).

Kalimantan
Barambai S. Kalimantan, Female, MZB 11114 (3.08 S, 114.64 E)
Barambai S. Kalimantan, Male, MZB 11115 (3.08 S, 114.64 E)
S. Kambat,Cerbon-S. Kalimantan, Male, MZB 22418, MZB 22419, MZB 22424, MZB 22429 (3.06 S, 114.70 E)
S. Kambat,Cerbon-S. Kalimantan, Female, MZB 22420, MZB 22421, MZB 22422, MZB 22423, MZB 22425, MZB 22432, MZB 22433, MZB 22434 (3.06 S, 114.70 E)
Singkawang, Female, MZB 4162 (0.90 N, 109.00 E)
Tepian Batang (Pasir) Samarinda, Female, MZB 6390, MZB 6391 (0.50 S, 117.15 E).

Sulawesi
Loewoe (Kalonisatie Bone-Bone), Male, MZB 6412, MZB 6413 (2.50 S, 120.75 E)
Makasar, Female, WAM 33095, (6.28 S, 119.87 E)
Makasar, Male, WAM 33354, (6.28 S, 119.87 E)
Makasar, Female, MZB 4876, MZB 4877, MZB 4879 (5.12 S, 119.40 E)
Makasar, Sulawesi, Male, MZB 4878, MZB 2355 (5.12 S, 119.40 E)

Bali
Bali, Male, MZB 17229, MZB 17232, MZB 17236 (8.50 S, 115.27 E)
Bali, Female, MZB 17231, MZB 17233, MZB 17234, (8.50 S, 115.27 E)
Bali, Male, MZB 17237 (8.15 S, 114.43 E)
Klungkung Male, MZB 197, MZB 201 (8.53 S, 115.40 E).

Lombok
Kuta Lombok, Female, MZB 17200 (8.92 S, 116.25 E)
Swda lombok, Male, MZB 4914 (8.75 S, 116.50 E)

Sumbawa
Desa Dahu, Male, MZB 17185, MZB 17186 (8.75 S, 118.43 E)

Desa Dahu, Female, MZB 17187, MZB 17188, MZB 17191 (8.75 S, 118.43 E)
Desa teluk Santong, Female, MZB 17182, (8.73 S, 117.89 E)
Dompoe, Soembawa., Female, MZB 4916, MZB 4917, MZB 4919, MZB 4921 (8.53 S, 118.47 E)

Sangeang
Desa Santong, Sangeang Is., Female, MZB 17184 (8.22 S, 119.01 E)
Desa Santong, Sangeang Is, Male, MZB 17183 (8.22 S, 119.01 E)
Dompoe, Soembawa, Male, MZB 4918, MZB 4920 (8.53 S, 118.47 E).

Sumba
Kananggar E. Sumba, Female, MZB 839 (10.05 S, 120.37 E)
Kambaniru, Female, MZB 4924, MZB 4939, MZB 4941, MZB 4942 (9.65 S, 120.32 E)
Melolo, Female, MZB 4931, (9.88 S, 120.67 E)
Sumba, Male, MZB 17165, MZB 17167, MZB 17168, MZB 17175 (9.63 S, 119.53 E)
Waikabubak, Male, MZB 17172, MZB 17177, (9.63 S, 119.53 E)
Waikabubak, Sumba, Female, MZB 17176, MZB 17178, MZB 17179 (9.63 S, 119.53 E)

Flores
Horowura Boru, Male, MZB 17195, (8.55 S, 123.65 E)
Kelimutu Woloaru, Female, MZB 17192, (8.70 S, 121.90 E)
Manggarai, Male, MZB 4923 (8.50 S, 120.25 E)
Maumere, Female, MZB 10492 (8.62 S, 122.23 E)
Mboera, Female, MZB 2396, MZB 2398 (8.57 S, 119.87 E)
Mboera, Male, MZB 2397, MZB 2399 (8.57 S, 119.87 E)
Wai Sano, Female, MZB 2401 (8.66 S, 120.51 E)
Wai Sano, Male, MZB 2402, MZB 2403 (8.66 S, 120.51 E)

Lembata
Belang Watokobu, Female, MZB 17193 (8.43 S, 123.37 E)

Adonara
Waiwerang, Horowura, MZB 17194 (8.33 S, 123.15 E)

Rinca
Rinca, Female, MZB 17196 (8.65 S, 119.67 E)

Tanimbar Is
Tanimbar, Male, WAM 43645, WAM 43653, WAM 43674, WAM 44390 (7.61 S, 131.46 E)
Tanimbar, Female, WAM 44317, WAM 43652 (7.61 S, 131.46 E)

Timor
Camplong Male, MZB 22413, MZB 22415, (10.03 S, 123.92 E)
Camplong Female, MZB 22414, MZB 22416 (10.03 S, 123.92 E)
Gunung Mutis, Timor, Male, MZB 17201 (9.55 S, 124.22 E)
Timor, Female, MZB 16747 (10.07 S, 123.88 E)

Alor
Alor, Male, MZB 17206, MZB 17207, MZB 17210, MZB 17214, MZB 17215 (8.25 S, 124.72 E)
Alor, Female, MZB 17208, MZB 17211, MZB 17212, MZB 17213, MZB 17219, MZB 17225, MZB 17226 (8.25 S, 124.72 E)

Komodo
Female, MZB 9001 (8.60 S, 119.50 E)
Male, MZB 9002 (8.60 S, 119.50 E)

Papua
Tanah Merah, Female, MZB 4875 (2.40 S, 140.35 E)

Records of the Western Australian Museum **22**: 67–74 (2003).

Second species of *Mangkurtu* (Spelaeogriphacea) from north-western Australia

Gary C. B. Poore [1] and W. F. Humphreys [2]

[1] Museum Victoria, PO Box 666E, Victoria 3001, Australia
email: gpoore@museum.vic.gov.au

[2] Western Australian Museum, Francis Street, Perth, Western Australia 6000, Australia
email: humphw@museum.wa.gov.au

Abstract – A new species, *Mangkurtu kutjarra*, is described, the second in this genus from Australia, and fourth living in the Order Spelaeogriphacea in the world. It occurs in a calcrete aquifer very close to that in which its congener lives in the Pilbara, Western Australia. Spelaeogriphacea, like Thermosbaenacea are thought to be relicts of a more widespread shallow-water marine Tethyan fauna stranded in interstitial or ground-water environments during periods of marine regression.

INTRODUCTION

Over the last few years an extraordinary diversity of stygal animals has been recorded from arid parts of Western Australia occupying both anchialine ecosystems and continental groundwaters (Humphreys, 1999, 2001), both fresh and saline. As is the case globally, these species largely comprise crustaceans, but a diversity of dytiscid beetles (Cooper *et al.*, 2002; Watts and Humphreys, 1999) and hydrobiid gastropods is also notable.

Amongst this fauna, *Mangkurtu mityula* Poore and Humphreys, 1998, from the Millstream (Western Fortescue Plain) aquifer in the Pilbara, was the first record of Spelaeogriphacea from Australia. This order was first described (*Spelaeogriphus lepidops* Gordon, 1957) from a sandstone cave at an altitude of 700 m on Table Mountain, South Africa. This remained the only record until another member of the order was found in a cave in the Mato Grosso in western Brazil (*Potiicoara brasiliensis* Pires, 1987). The Millstream species is the only species known to be widely present in a major aquifer where it is found together with a range of other Gondwanan freshwater lineages (Poore and Humphreys, 1998). The occurrence of fossil species of purported spelaeogriphaceans, *Acadiocaris novascotica* (Copeland, 1957) in Carboniferous marine sediments in Canada (Schram, 1974), and in lacustrine deposits of Jurassic age in China (*Lianongogriphus quadripartitus* Shen *et al.*, 1998) suggests that invasion of fresh water occurred prior to the dissolution of Pangaea and long before the fragmentation of Gondwana (Poore and Humphreys, 1998).

A Tethyan fauna, allied to the stygofauna of the Cape Range peninsula and Barrow Island (Humphreys, 2000), intrudes towards Millstream from the coast and is present in aquifers of the lower reaches of the Robe and Fortescue Rivers. Elements of this fauna reach an altitude of c. 300 m in the Robe River (Humphreys, 2001), the approximate level of the Late Eocene sea-level high in south-western Australia (G.W. Kendrick, personal communication 1999).

Here, a second species of the Australian genus is described from material collected in the same region as the first. Its environment is described. Sampling was conducted and water quality measured as detailed elsewhere (Watts and Humphreys, 2000). Material is lodged in the Western Australian Museum, Perth (WAM) and Museum Victoria, Melbourne (NMV).

Order Spelaeogriphacea Gordon, 1957

Family Spelaeogriphidae Gordon, 1957

Mangkurtu Poore and Humphreys, 1998

Remarks

Mangkurtu is unique among spelaeogriphacean genera in the possession of a digitiform maxillipedal epipod and in having endopodal lobes on the pleopods. The new species is similar in these respects and in many others to *M. mityula*, type species, but differs in the proportions and shapes of some morphological features. We do not reillustrate mouthparts but microscopic examination and SEMs provided to us by G.D.F. Wilson show no important differences. *Mangkurtu* is the only spelaeogriphid genus with more than one species.

In Poore and Humphreys' (1998) diagnoses of the

three extant genera the length of the antennal 2 scale was compared to peduncular article 3. It is now apparent that this "article 3" is in fact articles 3 and 4 together. No authors, including ourselves, have illustrated the very short article 3 of spelaeogriphaceans and have treated the antenna 2 peduncle as having four articles. We were able to confirm a similar very short article 3 visible only ventrally in a specimen of *Spelaeogriphus*. Spelaeogriphaceans have five antennal articles like all eumalacostrans (Figure 1c). We are now able to confirm that oostegites occur on pereopods 1–5 on this species as in other spelaeogriphaceans. Juveniles of the new species possess a reduced pereopod 7 (Figure 1e) and we assume that this manca stage, hitherto unreported, is general for spelaeogriphaceans. Embryos flex dorsally.

Gordon's (1957) figures of maxilla 2 of *Spelaeogriphus lepidops* suggest a pattern of setation on the outer endites different from that in *Mangkurtu*. We were able to observe that the triangular setae drawn by her are in fact just the tips of much longer curved setae, similar to those seen in the other genera.

Mangkurtu kutjarra sp. nov.

Figures 1–3

Material examined

Holotype

Western Australia. Pilbara Region, Fortescue River Valley, Roy Hill Station, Battle Hill Well, 22°44'28"S, 120°07'37"E, W.F. Humphreys and J.M. Waldock, 8 September 2000 (stn BES 8505), WAM C29101 (male, 4.5.mm, with 5 slides).

Paratypes

Collected with holotype, WAM C29102 (female with oostegites, 4.5 mm) C29103 (female with oostegite buds, 3.6.mm, with 3 slides), C29104 (juvenile, 4.0.mm), C2915 (2 males, 4.0, 4.6 mm), C29106 (female with oostegites and 16 eggs), C29107 (4 females, incomplete), C29108 (20 juveniles and mancas, incomplete); NMV J57461 (male), J57462 (male, 4.5 mm), J57463 (female with oostegite buds, 3.6 mm), J57464 (male, 4.2 mm), J57465 (male, 4.2 mm), J57466 (juvenile). Same area and date, Aerodrome Bore, 22°42'53"S, 119°54'53"E (stn BES 8501), NMV J57467 (male, 2 females, 2 juveniles).

Description

Male. Ratio of carapace : pereon : pleon ratio 1 : 1.9 : 3.2. Telson 1.2 times as long as wide at base, tapering to semicircular apex with three pairs of marginal spiniform setae, first pair (most lateral) the longest; and 1 shorter pair submarginal-dorsal between 2 most lateral setae.

Antenna 1 total length 0.65 of body; outer flagellum with c. 37 articles; inner flagellum of 30 articles.

Antenna 2 1.5 times length of body; peduncle article 2 with distolateral row of stout setae; article 3 very short; article 4 longer than article 2; article 5 longer than 4, with distal setae; exopod width 0.30 length, with medial rows of alternating eight plumose and eight stout setae.

Pereopods 1–7 similar to those of *M. mityula*, endopod and exopods of similar proportions, bases of 5–7 with similar pedunculate setae. Distal margins of carpi of all pereopods with oblique row of falcate setae mounted on conical projections: nine or ten on pereopods 1–3, four–seven on pereopod 4; propodi with groups of one–three similar setae.

Penes at bases of pereopods 7 cylindrical, stout, meeting in midsternum.

Pleopod 2 exopod two-articulate, shorter than endopod; proximal article with one lateral simple seta, one distolateral plumose and one distomesial plumose setae; distal article with 18 marginal plumose setae and 13 shorter simple setae on distal margin; endopod broadly-falcate, curving laterally to enclose exopod, with one proximomesial and 4 midmesial setae.

Uropod peduncle with four distolateral, 2 distomesial, one proximomesial spiniform setae, one simple and one plumose setae ventrally on distal margin; endopod with 22 marginal plumose setae and two or three submarginal dorsal setae; exopod two-articulate; proximal article longer than endopod, with four distolateral, six mesial spiniform setae; distal article twice as long as wide, with 26 marginal plumose setae, one simple apical setae.

Manca. Pereonite 7 apparent as a single article.

Ovigerous female. Ratio of carapace : pereon : pleon ratio 1 : 2.5 : 2.7. Pleopod 2 similar to pleopods 1 and 3; oostegites on pereopods 1–5, carrying in one case 16 eggs and in another four embryos. Embryos flex dorsally.

Etymology

Kutjarra, meaning two in the Australian Aboriginal language of the Western Desert, alluding to the second species in the genus.

Distribution

Roy Hill calcrete, Pilbara, Western Australia.

Remarks

Mangkurtu kutjarra differs from *M. mityula* in the shape of the telson (more tapered and with a more rounded apex, four rather that five pairs of distal marginal setae), proportions of the uropod (endopod shorter and relatively wider, with more

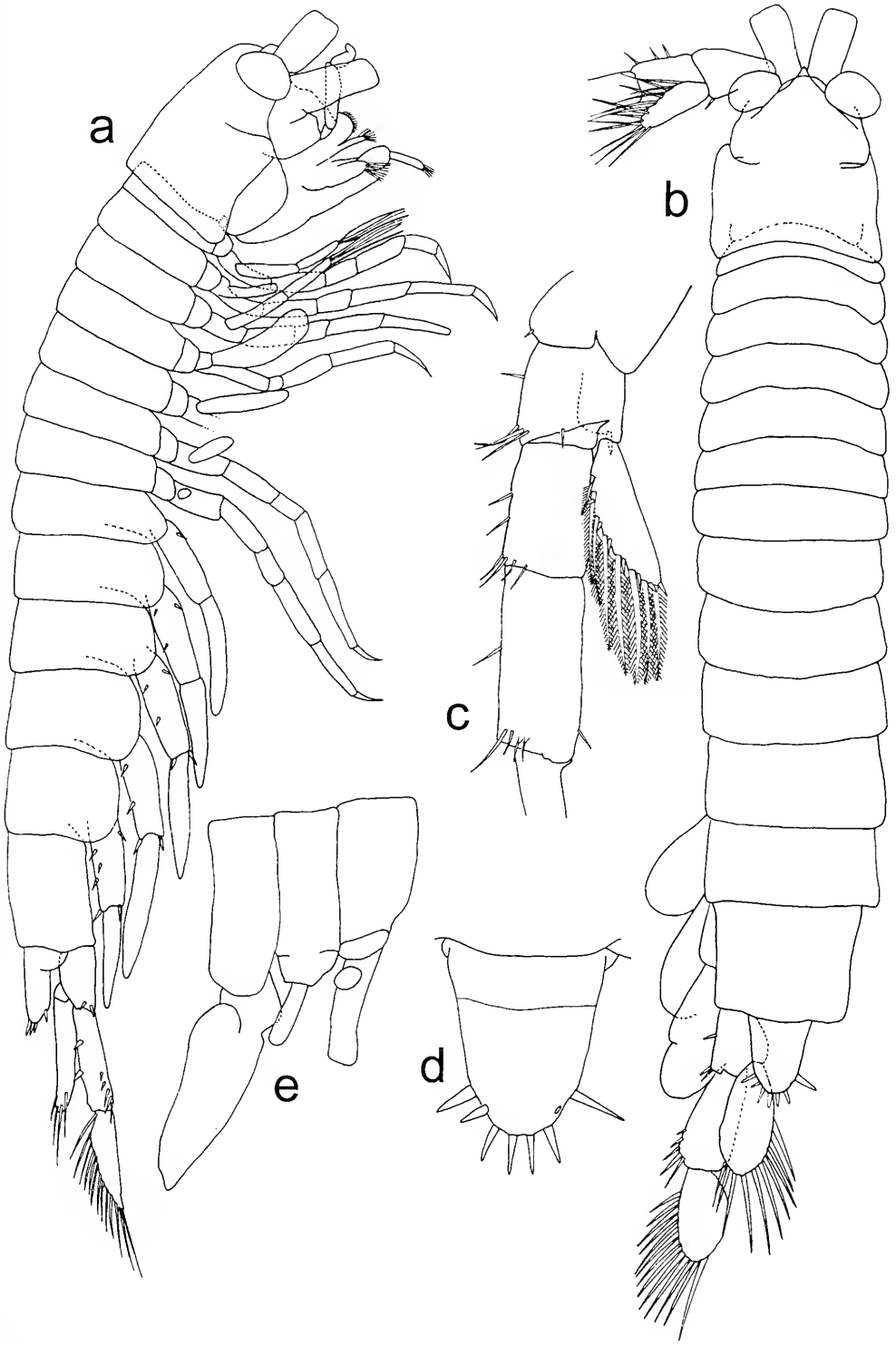


Figure 1 *Mangkurtu kutjarra* n. sp. Holotye male, 4.5 mm, WAM C29101. a, b, habitus (scale 0.5 mm); c, antenna 2 peduncle; d, telson. Manca, WAM C29108. e, (right to left) pereonites 6 and 7, pleonite 1 with basis of pereopod 6, pereonite 7, and peduncle of pleopod 1.

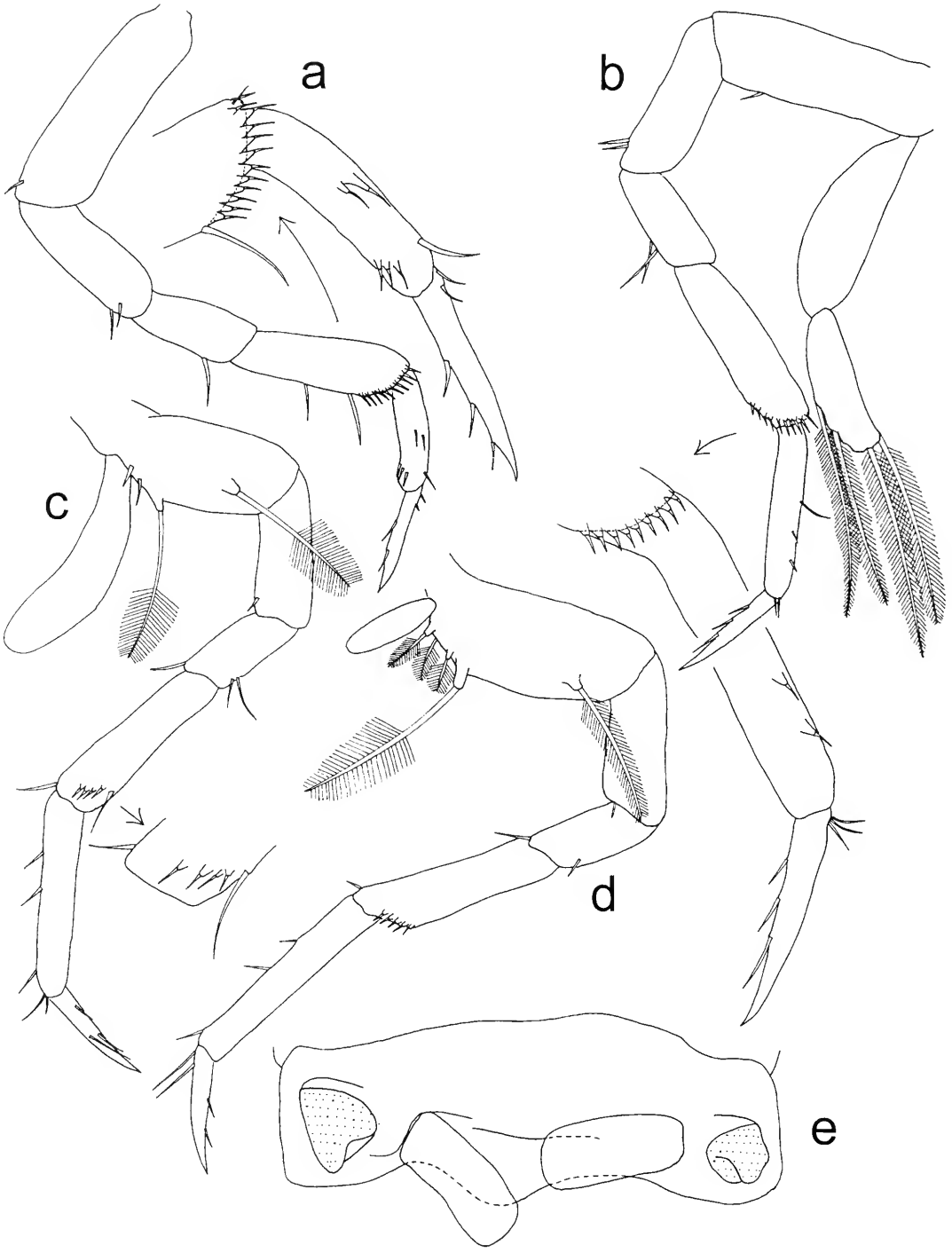


Figure 2 *Mangkurtu kutjarra* n. sp. Holotype male, 4.5 mm, WAM C29101. a–d, pereopods 1, 2, 4 and 6 with details of distal articles; e, ventral view of pereonite 7 with penes.

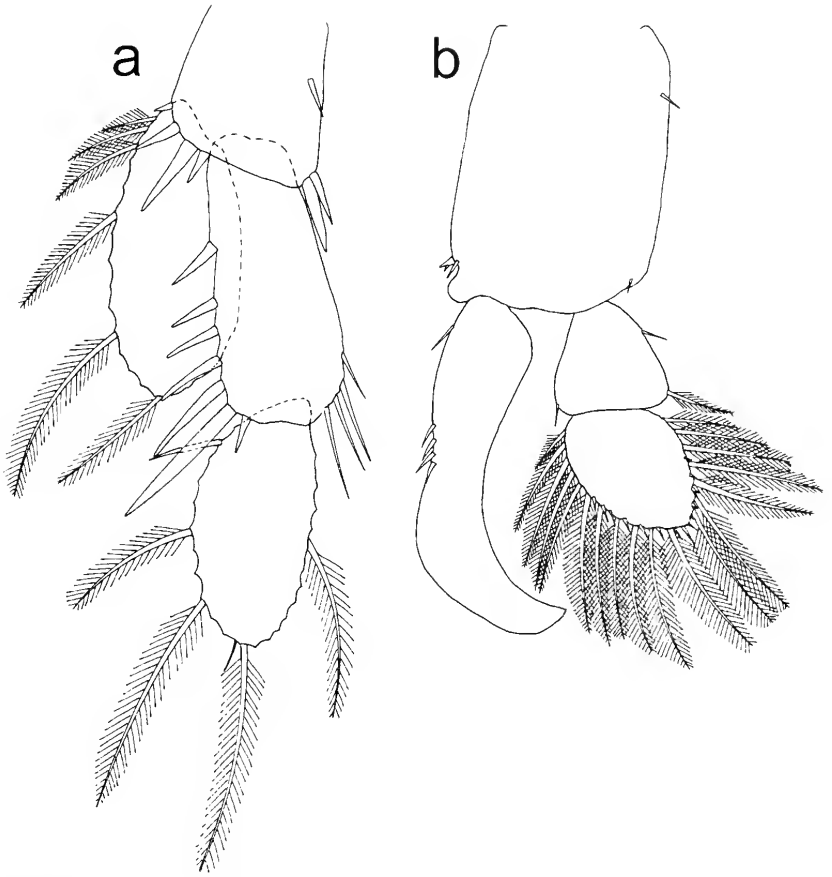


Figure 3 *Mangkurtu kutjarra* n. sp. Holotype male, 4.5 mm, WAM C29101. a, uropod; b, pleopod 2.

setae), and shape of the male pleopod 2 endopod (much more curved and broader).

The environment

The Fortescue Valley extends for 450 km as a broad plain trending west-north-west between the Hamersley and Chichester Ranges in the Pilbara, the northern craton of the 'Western Shield' of Australia. The upper part of the river and its tributaries drain the Archaean ranges to the Cainozoic surficial alluvial deposits in the Fortescue Valley.

The Fortescue Valley contains several discrete groundwater calcrete deposits, the larger being those at Roy Hill and the Western Fortescue Plain (Millstream, a lacustrine calcrete of Tertiary age)—the nature of these calcretes is discussed elsewhere in the context of stygofauna (Humphreys, 1999; 2001). Further calcrete bodies occur downstream of Roy Hill, successively at Mulga Downs, Mount Florance and Millstream, the latter being the habitat of *Mangkurtu mityula*, before the river descends through groundwater gaps to the coastal plain. Sampling has not detected spelaeogriphaceans in the Mulga Downs and Mount Florance calcretes, although other stygofauna do occur there.

Mangkurtu kutjarra occurs in a groundwater calcrete aquifer on Roy Hill pastoral station in the upper Fortescue Valley (Figure 4), immediately upstream of the Fortescue Marsh which generally comprises a salt lake (playa). The Fortescue Marsh is now an internal drainage basin within the Fortescue palaeodrainage and even in times of peak flow – following rare episodic rainfalls, when an extensive lake may form lasting many months to several years – it does not discharge downstream. Consequently, the area accumulates salt from aerial deposition and contains hypersaline groundwater. Floods that do recharge the Millstream aquifer downstream result from flows of the South Fortescue River. Hence, the Millstream aquifer is now probably isolated from those upstream in the Fortescue Valley, including the Roy Hill calcrete. In the Eocene the Fortescue Marsh drained externally through the current Robe River and a variety of evidence, though not conclusive, suggests that the

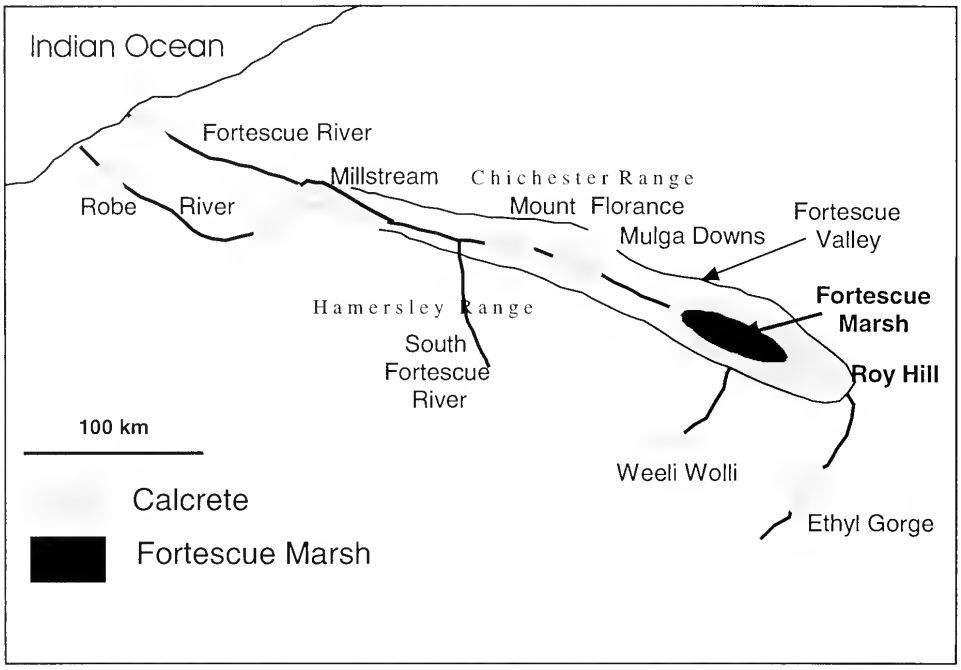


Figure 4 Schematic diagram of the Fortescue Valley and the spatial relationship of the Roy Hill calcrete area to other calcretes in the drainage system and the Fortescue Marsh.

Marsh could have been essentially internally draining since the Miocene. However, the groundwater system is still continuous and the amount of salt in the hypersaline groundwater in the Marsh suggests that there have been exceptional wet periods in which the marsh overflowed to the west (D.P. Commander, personal communication 2003).

The water inhabited by *Mangkurtu kujarra* is slightly saline and with low oxygen saturation but with a pH typical of calcrete areas (Table 1). It is not known whether the water column is highly stratified with respect to salinity as found in some other arid areas of Western Australia (Watts and Humphreys, 2000; Humphreys, 2002).

Table 1 Site description and water quality at two collection sites from which *M. kutjarra* was taken at Roy Hill Station, Fortescue River Valley, Pilbara Region, WA.

Parameter	Battle Hill Well	Aerodrome Bore
Site description	Well maintained, uncovered, cement-lined well on raised stone plinth	Overgrown, open borehole, fetid
Conductivity (mS cm^{-1})	6.65	5.67
Salinity (g L^{-1})	3.94	3.36
Temperature (°C)	25.5	29.2
O_2 (mg L^{-1})	1.5	0.71
O_2 saturation (%)	18.6	9.2
pH	7.13	7.20
Depth to water (m)	3.6	9
Depth of water (m)	4.0	2.0

BIOGEOGRAPHIC AND CONSERVATION IMPLICATIONS

The presence of isolated populations of separate species of spelaeogriphaceans suggests that the groundwater calcrete deposits have long been separated from each other. Similar speciation is seen amongst stygal Dytiscidae (Insecta: Coleoptera) in the Yilgarn (the southern part of the Western Shield) where both morphological and molecular evidence support the thesis that the calcretes form separate islands of groundwater, many containing a unique fauna (Watts and Humphreys, 1999, 2000, 2001; Cooper *et al.*, 2002). This appears to be the case there also with stygal *Haloniscus* (Crustacea: Isopoda: Oniscidea) which occurs as sympatric congeners (Taiti and Humphreys, 2001).

The Fortescue calcrete aquifers contain numerous new genera and species of Candoninae (Crustacea:

Ostracoda): one an undescribed genus from the Roy Hill calcrete as yet unknown elsewhere, others species from the calcretes upstream (Ethyl Gorge) representing two different undescribed genera, while a further two undescribed genera occur downstream of Roy Hill, from Mulga Downs to the coast. Furthermore, a tributary joining the central Fortescue Marsh (Weeli Wolli Creek) contains a further two undescribed genera (I. Karanovic, personal communication). In addition, isopods of the genus *Pygolabis*, second genus of the enigmatic family Tainisopidae first described from the Kimberley (Wilson and Ponder, 1992), are represented by at least four species (Wilson, 2003) in separate calcretes found in drainages to the main Fortescue Valley.

The occurrence of distinct faunas in the discrete deposits of groundwater calcrete on the Western Shield has become contentious owing to the conservation implications of numerous discrete faunas in shallow unconfined groundwaters in an arid but mineraliferous region. For example, numerous species of *Chydaekata* (Amphipoda: Paramelitidae) have been described from the calcretes of the upper Fortescue River, at Ethyl Gorge (Bradbury, 2000) but thus far these have not been corroborated by electrophoretic data. Among the diverse copepod fauna of the Yilgarn (Karanovic, in press), many species have quite widespread distributions, not being confined to single calcretes. It is not unexpected to find a diversity of responses amongst lineages of different ages and ecologies in response to the evolution of this ancient landscape.

Biogeographic implications

Present-day Thermosbaenacea (which comprise only 34 species in total) are thought to be relicts of a more widespread shallow-water marine Tethyan fauna (Wagner, 1994), stranded in interstitial or ground-water environments during periods of marine regression. The same hypothesis has been applied to other taxa such as stygiobiont Amphipoda (Stock, 1993) and the copepod genus *Misophriopsis* (Boxshall and Jaume, 2000). This hypothesis can be extended to the four spelaeogriphacean species and the existence of a supposed marine fossil, *Acadiocaris novascotica* (Copeland, 1957) from the Carboniferous in Canada (Schram, 1974), gives some support.

This is consistent with the intrusion of Tethyan fauna, especially *Halosbaena tulki* (Thermosbaenacea), up the Robe River, the fomer Fortescue drainage and close to *Mangkurtu mityula* sites, to an altitude of c. 300 m (Humphreys, 2001), the approximate level of the Late Eocene sea-level high in south-western Australia (G.W. Kendrick, personal communication 1999). However, the three extant genera of Spelaeogriphacea all occur on parts of the continents that have not been inundated by the sea since the dissolution of Gondwana, which commenced with the separation of east- and west-Gondwana (142–133 Ma: Partridge and Maud, 1987). Each species now occurs with a very circumscribed distribution in subterranean freshwater habitats on Gondwanan fragments (Africa, South America and Australia) (Poore and Humphreys, 1998). While both *Mangkurtu* and *Spelaeogriphus* locations may have abutted the shoreline of Cretaceous or Late Jurassic marine incursions (Scotese, 1998), such proximity in the case of *Potiicoara* in the southern Mato Grosso, Brazil, is obscure. The sites lie in an extensive karst area cut by the Rio Paraguai valley at an altitude of only c. 330 m, despite lying nearly 1000 km inland, and the cave waters inhabited descends about 200 m (Moracchioli, 2002). Hence the area may have abutted Eocene shores and a clear marine intrusion into the region in the Late Miocene (10 Ma) and less clearly in the Palaeocene (60 Ma) directly from western Tethys was shown by Smith *et al.* (1994).

ACKNOWLEDGEMENTS

We thank the lessees of the pastoral stations for facilitating access and Julianne Waldock for wonderful support in the field and the laboratory. For specimens of the extant non-Australian Spelaeogriphacea we thank Nicoletta Moracchioli and Norma Sharratt. We thank G.D.F. (Buz) Wilson, Australian Museum, Sydney for allowing us to see the SEMs prepared by him. Field work was funded by the *BankWest Landscape Conservation Visa Card Trust Fund Grants.*

REFERENCES

Boxshall, G.A. and Jaume, D. (2000). Discoveries of cave misophioirds (Crustacea: Copepoda) shed new light on the origin of anchialine faunas. *Zoologischer Anzeiger* **239**: 1–19.

Bradbury, J.H. (2000). Western Australian stygobiont amphipods (Crustacea: Paramelitidae) from the Mt Newman and Millstream regions. *Records of the Western Australian Museum, Supplement* **60**: 1–102.

Cooper, S., Hinze, S., Leys, R., Watts, C.H.S. and Humphreys, W.F. (2002). Islands under the desert: molecular systematics and evolutionary origins of stygobitic water beetles (Coleoptera: Dytiscidae) from central Western Australia. *Invertebrate Systematics* **16**: 589–598.

Copeland, M.J. (1957). The Carboniferous genera *Palaeocaris* and *Euproops* in the Canadian maritime provinces. *Journal of Paleontology* **31**: 595–99.

Gordon, I. (1957). On *Spelaeogriphus*, a new cavernicolous crustacean from South Africa. *Bulletin of the British Museum of Natural History (Zoology)* **5**: 31–47.

Humphreys, W.F. (1999). Relict stygofaunas living in sea salt, karst and calcrete habitats in arid northwestern

Australia contain many ancient lineages. In: Ponder, W.F., and Lunny, D. (eds), *The other 99%. The conservation and biodiversity of invertebrates*. Royal Zoological Society of New South Wales, Mossman. Pp. 219–227.

Humphreys, W.F. (2000). The hypogean fauna of the Cape Range peninsula and Barrow Island, northwestern Australia. In: Wilkins, H., Culver, D.C., and Humphreys, W.F. (eds), *Ecosystems of the World*. Elsevier, Amsterdam. Pp. 581–601.

Humphreys, W.F. (2001). Groundwater calcrete aquifers in the Australian arid zone: the context to an unfolding plethora of stygal biodiversity. In: Humphreys, W.F. and Harvey, M. S. (eds), Subterranean Biology in Australia 2000. *Records of the Western Australian Museum, Supplement* **64**: 63–83.

Humphreys, W.F. (2002). Groundwater ecosystems in Australia: an emerging understanding. *Proceedings of the International Association of Hydrogeologists Conference, Darwin, Australia 12–17 May 2002. CD-ROM.*

Karanovic, T. (in press). Subterranean copepods (Crustacea: Copepoda) from arid Western Australia. *Crustaceana Monographs* **3**.

Moracchioli, N. (2002). Estudo dos Spelaeogriphacea brasileiros, crustáceos Peracarida subterrâneos. Doutor em Ciências thesis, Instituto de Biociências da Universidade de São Paulo, São Paulo.

Partridge, T.C. and Maud, R.R. (1987). Geomorphic evolution of southern Africa since the Mesozoic. *South African Journal of Geology* **90**: 179–208.

Pires, A.M.S. (1987). *Potiicoara brasiliensis*: a new genus and species of Spelaeogriphacea (Crustacea: Peracarida) from Brazil with a phylogenetic analysis of the Peracarida. *Journal of Natural History* **21**: 225–238.

Poore, G.C.B. and Humphreys, W.F. (1998). First record of Spelaeogriphacea from Australasia: a new genus and species from an aquifer in the arid Pilbara of Western Australia. *Crustaceana* **71**: 721–742.

Schram, F.R. (1974). Paleozoic Peracarida of North America. *Fieldiana Geology* **33**: 95–124.

Scotese, C.R. (1998) *Paleogeographic Atlas. PALEOMAP Project*. University of Texas, Arlington.

Shen, Y.-b., Taylor, R.S. and Schram, F.R. (1998). A new spelaeogriphacean (Crustacea: Peracarida) from the Upper Jurassic of China. *Contributions to Zoology* **68**: 19–35.

Smith, A.G., Smith, D.G. and Funnell, B.M. (1994). *Atlas of Mesozoic and Cenozoic coastlines*. Cambridge University Press, Cambridge.

Stock, J.H. (1993). Some remarkable distribution patterns in stygobiont Amphipoda. *Journal of Natural History* **27**: 807–819.

Taiti, S. and Humphreys, W.F. (2001). New aquatic Oniscidea (Crustacea: Isopoda) from groundwater calcretes of Western Australia. *Records of the Western Australian Museum, Supplement* **64**: 133–151.

Wagner, H.P. (1994). A monographic review of the Thermosbaenacea (Crustacea: Peracarida). *Zoologische Verhandelingen, Leiden* **291**: 1–338.

Watts, C.H.S. and Humphreys, W.F. (1999). Three new genera and five new species of Dytiscidae (Coleoptera) from underground waters in Australia. *Records of the South Australian Museum* **32**: 121–142.

Watts, C.H.S. and Humphreys, W.F. (2000). Six new species of *Nirridessus* and *Tjirtudessus* (Dytiscidae; Coleoptera) from underground waters in Australia. *Records of the South Australian Museum* **33**: 127–144.

Watts, C.H.S. and Humphreys, W.F. (2001). A new genus and six new species of Dytiscidae (Coleoptera) from underground waters in the Yilgarn palaeodrainage system of Western Australia. *Records of the South Australian Museum* **34**: 99–114.

Wilson, G.D.F. (2003). A new genus of Tainisopidae fam. nov. (Crustacea: Isopoda) from the Pilbara, Western Australia. *Zootaxa* **245**: 1–20.

Wilson, G.D.F. and Ponder, W.F. (1992). Extraordinary new subterranean isopods (Peracarida: Crustacea) from the Kimberley region, Western Australia. *Records of the Australian Museum* **44**: 279–298.

Manuscript received 23 April 2003; accepted 18 June 2003

Records of the Western Australian Museum **22**: 75–80 (2003).

A new species of ingolfiellid amphipod (Crustacea: Amphipoda) from Western Australia

Susana Gallego Martínez and Gary C. B. Poore

Marine Biology Section, Museum Victoria, GPO Box 666E, Melbourne, Victoria 3001, Australia
emails: sgallego@museum.vic.gov.au; gpoore@museum.vic.gov.au

Abstract – A third species, *Ingolfiella quokka* sp. nov., is added to the Australian fauna, the first from Western Australia. The new species is from an intertidal sandy beach environment; previously described Australian species inhabit the marine shelf of south-eastern Australia.

INTRODUCTION

The ingolfiellidean amphipods are a small group of about 30 species included in two families, the monotypic Metaingolfiellidae, and Ingolfiellidae. Their distribution ranges from the deep sea through shallow marine sediments and intertidal sands to freshwater springs and caves. The presence of an "eye-lobe" distinguishes the suborder Ingolfiellidea from other suborders of the order Amphipoda. While it is probable that the group is monophyletic their phylogenetic isolation from Gammaridea in particular is questionable (Lowry and Poore, 1989; Dahl, 1977). Stock (1979; 1977; 1976), Dojiri and Sieg (1987), and Ruffo and Taglianti (1989) have studied the systematics and zoogeography of the group. Stock (1976) divided the family Ingolfiellidae into three genera, and the largest genus, *Ingolfiella*, into subgenera. The question of subgenera was addressed again by Ruffo and Taglianti (1989). Lowry and Poore (1989) had difficulty placing their two south-eastern Australian species unambiguously in any subgenus and questioned their usefulness. We do not add further to this debate, especially as the Ingolfiellidea as a whole are subject to a phylogenetically based reclassification (R. Vonk and F. Schram, personal communication, 2002).

A new species of ingolfiellids was discovered in samples taken on a sandy beach on Rottnest Island, Western Australia, and is here described. The material comprises 16 individuals, 2 males and 14 females. The description is a composite derived after dissection of several individuals. Types are lodged in the Western Australian Museum, Perth (WAM), and Museum Victoria, Melbourne (NMV). Abbreviations are as follows: A1, A2, antennae 1, 2; G1, G2, gnathopods 1, 2; MX1, MX2, maxillae 1, 2; MD, mandible; MP, maxilliped; P3–P7, pereopods 3–7; PL1–PL3, pleopods 1–3; r, right; l, left; UR1–UR3, uropods 1–3.

Ingolfiellidae Hansen, 1903

Ingolfiella quokka sp. nov.

Figures 1–3

Holotype

Female, 1.08 mm (WAM C33548 on 3 slides), City of York Bay (32°00'S, 115°36'E), Rottnest Island, Western Australia, sandy beach, S. Griffin, July 1991.

Paratypes

Female, 1.54 mm (WAM C33549); male, 1.25 mm (WAM C33550); female, 1.48 mm (WAM C33551, with 2 slides); female, 1.27 mm (WAM C33552); female, 1.08 mm (WAM C33553, with 1 slide); male, 1.06 mm (WAM C33554, with 2 slides); female, 0.87 mm (WAM C33555); female, 1.34 mm (WAM C33556); female, 1.38 mm (WAM C33557); female, 1.31 mm (WAM C33558); female, 0.91 mm (WAM C33559); female, 1.06 mm (WAM C33560); female, 1.26 mm (NMV J52442); female, 1.22 mm (NMV J52443); female, 0.78 mm (WAM C33561). All collected with holotype.

Description

Female (based on holotype, 1.08 mm, and paratype female, 1.48 mm). Body segments laterally compressed. Head, anterodorsal margin rounded, without rostrum; "eye-lobe" semicircular. Pereonite 1 about half as long as head; posteroventral margin oblique; deeper anteriorly than posteriorly such that pereonites 1 and 2 only weakly separated. Pereonites 2–7 increasing in depth posteriorly. Pleonites 1–3 with posteriorly rounded epimera. Urosomites 1 and 2 not markedly differentiated from pleonites, of similar length; urosomite 3 with lateral plates enclosing base of telson and uropod 3.

Antenna 1, peduncular article 1 as long as head; ratio of articles 1.0:0.4:0.3; flagellum of four articles,

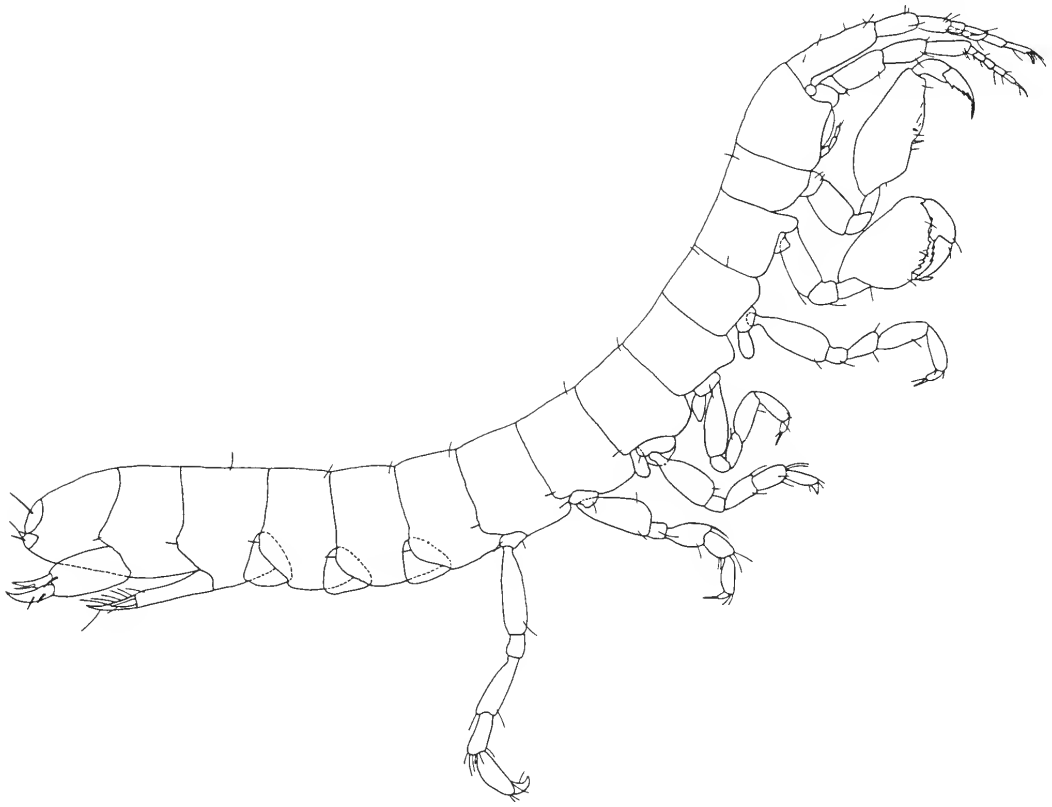


Figure 1 *Ingolfiella quokka* sp. nov., holotype female, WAM C33548; Rottnest Island, Western Australia.

slightly more than half length of peduncle, article 4 with one apical aesthetasc; accessory flagellum of three articles, last minute, reaching end of article 2 of flagellum. Antenna 2, peduncle as long as peduncle of antenna 1; ratio of articles 0.4:0.2:1.0:0.8:0.8; flagellum of five articles, slightly less than half length of peduncle, article 5 with one apical aesthetasc.

Mandible molar processes acute; spine row of two club-like spines; lacinia mobilis about two-thirds width of incisor process on left, half on right, each obscurely toothed; incisor process with five blunt teeth on left and right. Maxilla 1, inner plate blunt, with one seta; outer plate with four cuspidate setae, with three, two, three, five cusps respectively; palp of two articles, with two unequal apical setae. Maxilla 2, inner and outer plates each with four terminal setae. Maxilliped basal endite with two apical setae; palp articles 1–4 with three, one, one and one mesial setae respectively, article 5 with long falcate unguis, seta at midlength and at base of unguis.

Gnathopod 1 coxa at anterior of pereonite; carpus 2.4 times as long as wide, palm with three proximal spiniform setae, three pairs of pinnate setae at mid-palm, palm without teeth; dactylus with four teeth. Gnathopod 2 palm at 45° to longitudinal axis; carpus 1.7 times as long as wide; palm defined proximally by an obtuse angle bearing two spiniform setae (proximal one longer and more curved than other), three triangular teeth along palm, three flagellate spiniform setae and five simple setae; dactylus as long as palm, with four teeth on inner margin.

Pereopods 3 and 4, propodus with three distal setae; dactylus with two distal setae and cylindrical trifid unguis. Pereopods 5 and 6, merus with spiniform seta and simple seta; carpus with two distal long stout setae, two short stout and two slender setae; propodus with five distal setae on pereopod 6, and three setae on pereopod 5; dactylus with cylindrical bifid unguis. Pereopod 7, merus with one distal stout seta and two slender setae; carpus with one distal short stout seta, three long stout setae and three slender setae; propodus with three distal setae; dactylus stout, curved with one subtriangular spike at midlength, unguis not defined. Coxal gills ovate, small, on pereonites 3, 4, and 5. No oostegites.

Pleopods 1–3 subtriangular, without distal setae.

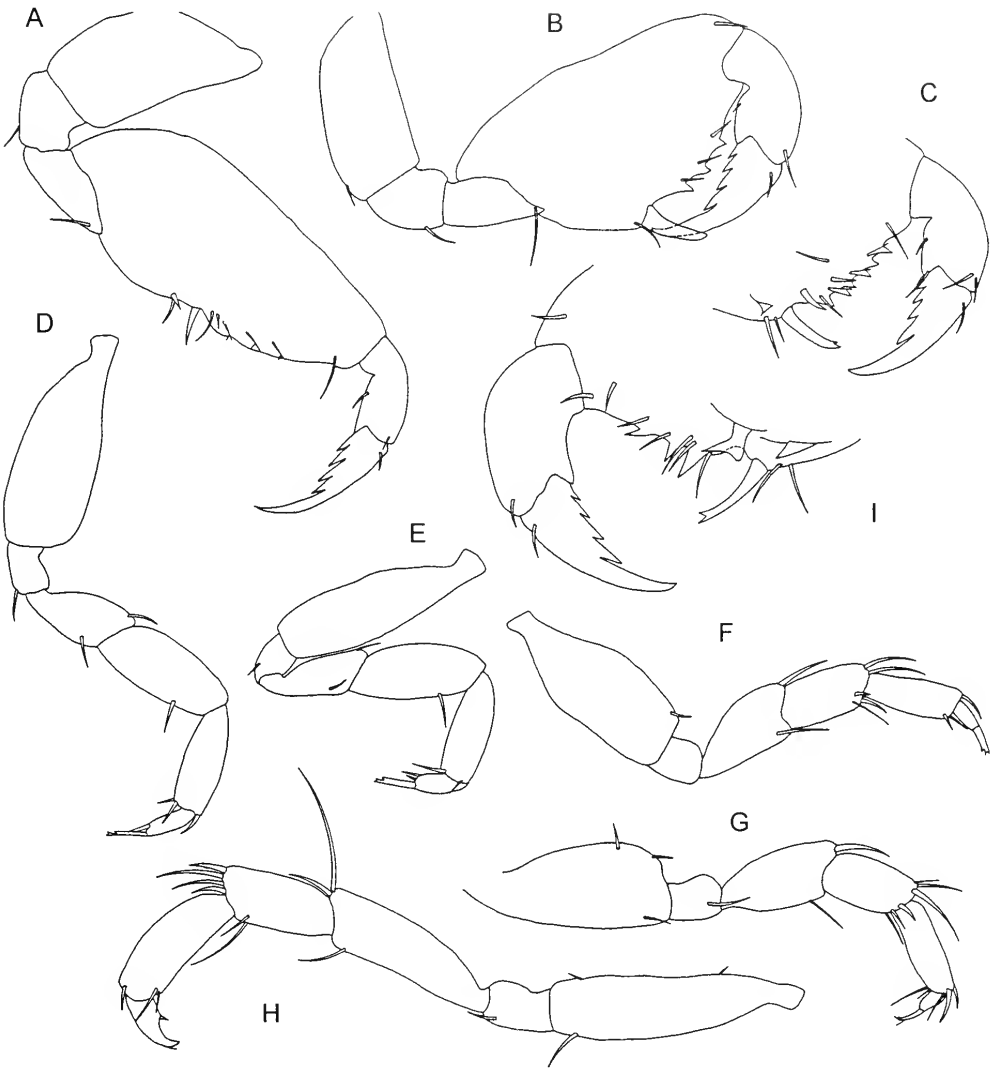


Figure 2 *Ingolfiella quokka* sp. nov. Paratype female, WAM C33551: **A**, left gnathopod 1; **B**, right gnathopod 2, lateral; **C**, left gnathopod 2 palm and dactylus, mesial; **D**, pereopod 3; **E**, pereopod 4; **F**, pereopod 5; **G**, pereopod 6; **H**, pereopod 7. Paratype male, WAM C33554: **I**, right gnathopod 2, palm and dactylus, mesial.

Uropod 1 peduncle with two distal setae, without a long reversed seta on lower margin; inner ramus 0.9 times length of peduncle, with lateral row of eight long setae, edges of apex finely denticulate; outer ramus half as long as inner ramus, with one subdistal seta. Uropod 2 peduncle with three obliquely transverse rows of (proximal to distal) nine, seven, nine complex setae; rami uniarticulate, outer 0.7 times length of peduncle, inner ramus 0.9 times length of outer ramus; outer ramus with three setae; inner ramus with two setae. Uropod 3 with one ramus; peduncle with three lateral setae, ramus short, broad, with long distal seta. Telson subsemicircular, with pair of long dorsal setae.

Male (based on paratype, 1.06 mm). As female except in the following. Gnathopod 2 carpus palm defined proximally by an obtuse angle bearing one long curved spiniform seta and more distally on inner surface one strong flaring tooth-like seta; palm with three subtriangular teeth and nine simple setae. Pleopods slightly narrower than in female; pleopod 1 only with two short distal setae. Uropod 2 peduncle with a short curved seta hooked distally

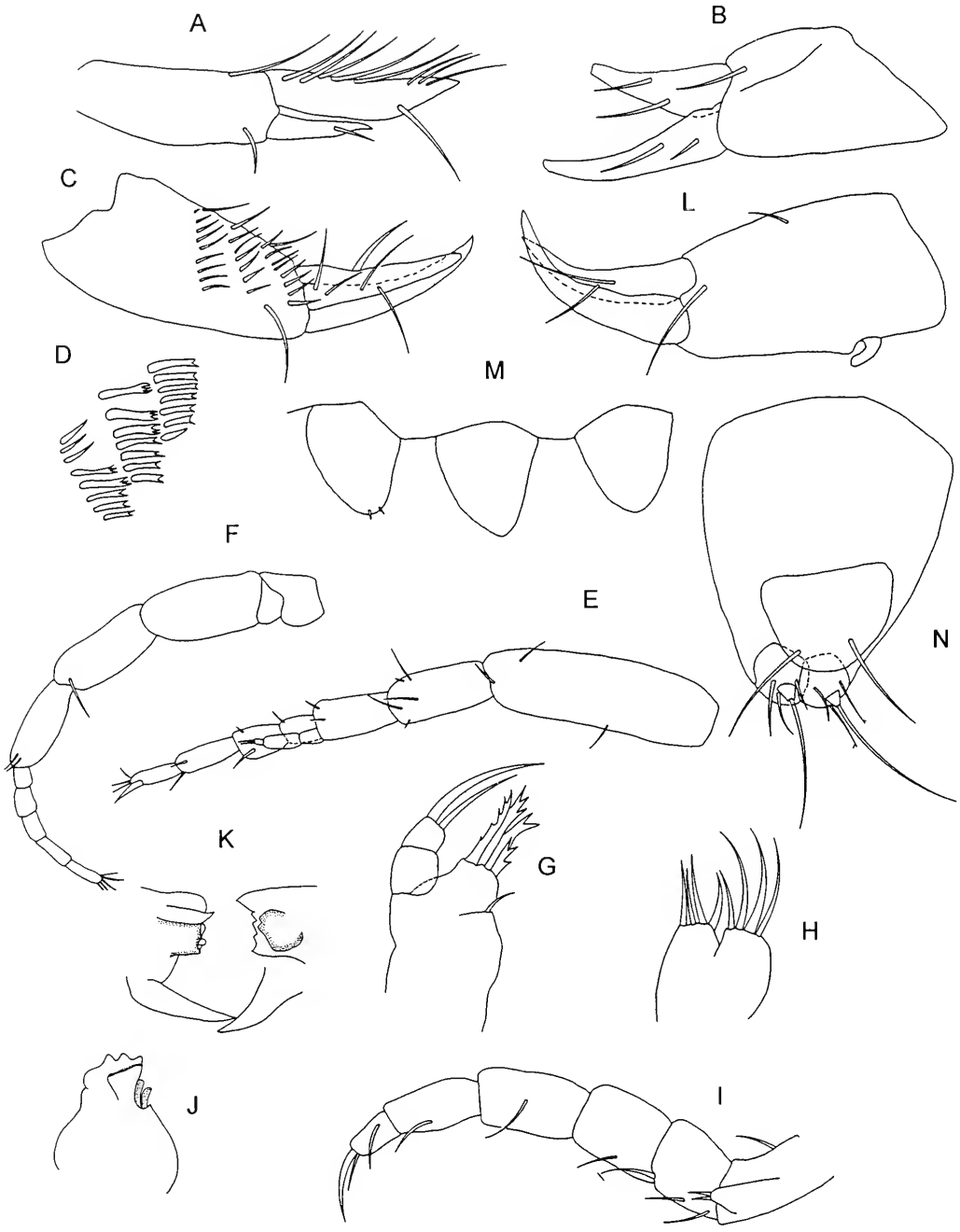


Figure 3 *Ingolfiella quokka* sp. nov. Paratype female, WAM C33551: **A**, uropod 1; **B**, right uropod 2, lateral; **C**, right uropod 2, mesial; **D**, detail complex setae on mesial face of uropod 2; **E**, antenna 1; **F**, antenna 2; **G**, maxilla 1; **H**, maxilla 2; **I**, maxilliped; **J**, mandible; **K**, ventral view of mandibles, anterior at top, lacinia mobilis on left and right stippled. Paratype male, WAM C33554: **L**, right uropod 2; **M**, pleopods 1–3; **N**, urosomite 3, dorsal view with telson and uropods 3.

to meet a broad triangular marginal projection of the lower margin.

Etymology

For the Quokka (*Setonix brachyurus*), a species of wallaby living on Rottnest Island in Western Australia and after which the island was named by Willem de Vlamingh in 1696.

DISCUSSION

Ingolfiella quokka is most similar to species that have been assigned to the subgenus *Antilleella* sharing characters such as a reduced or absent ocular lobe, subtriangular pleopod 1 modified in males with two apical setae, and similar pereopods 3–7. Of the species placed in this subgenus by Ruffo and Taglianti (1989) it is similar to *I. putealis, I. fontinalis, I. tabularis, I. margaritae, I. similis, I. unguiculata* and *I. beatricis* as follows: (1) possession of small ocular lobe (reduced or vestigial in most species of the subgenus, except for *I. similis* where it is absent and *I. beatricis* where it is developed); (2) antenna 1 flagellum of four articles and with three-articled accessory flagellum; (3) serrated palmar margin of gnathopod 2 (variously eight teeth in *I. similis*, smooth margin in *I. beatricis*); (4) gnathopod 2 sexually dimorphic; (5) gnathopods 1 and 2 dissimilar; (6) basofacial hook on peduncle uropod 2 in males; (7) subtriangular pleopods present (subtrapezoidal in *I. beatricis* and *I. unguiculata*), modified in males with two distal setae; and (8) uropod 2 with three obliquely transverse rows of spines (except for *I. putealis* with four rows and *I. fontinalis* with two rows).

Ingolfiella quokka differs from most species of the subgenus *Antilleella* in: (1) absence of a reversed modified seta in male gnathopod 2; (2) females without oostegites (except for *I. unguiculata* and *I. beatricis*) – unless supposed females of our and these species are not mature; (3) pereopods 3 and 4 unlike pereopods 5–7, that is, dactyli of pereopods 3 and 4 with long apically bifid unguis, dactyli of pereopods 5 and 6 with stronger bifid unguis, and pereopod 7 lacks unguis; (4) absence of a sharp inner spur distally on the basal part of dactyli; and (5) dactylus of gnathopods 1 and 2 with four serrations instead of three (except for *I. beatricis*).

The new species differs from *I. bassiana*, the only Australian species which could be placed in subgenus *Antilleella*. The complexity of the palmar spines on the male gnathopod 2, the plumose seta on the peduncle of uropod 1, and the two setae of the pleopod 2 in males sets *I. bassiana* apart from *I. quokka*.

Ingolfiella quokka has also some characters similar to *I. fuscina* Dojiri and Sieg, 1987, a species more akin to the subgenus *Tethydiella* Ruffo and Taglianti, 1989. These are: (1) gnathopod 1 carpus palm bearing Y-shaped setae; (2) gnathopod 1 dactylus with four teeth; (3) pereopods 3–4 unlike pereopods 5–7 (diagnostic of *Tethydiella*); (4) pereopods 3 and 4 dactyli with trifid unguis (unlike *Antilleella*, where the unguis is bifid); (5) absence of a sharp inner spur distally on the basal part of in pereopods 3–7 dactyli; and (6) the complex nature of the mesial spines on uropod 2. However, the new species can be distinguished from *I. fuscina* by: (1) absence of unguis in pereopod 7; (2) female probably devoid of oostegites (always present in *Tethydiella*); (3) sexual dimorphism in gnathopod 2; (4) subtriangular pleopods present in both sexes (lamelliform with one or two apical setae in *I. fuscina*); (5) male pleopod 1 subtriangular with two apical setae (only one in *I. fuscina*); (6) absence of terminal, dorsal, pectinate spine on male uropod 1 (uropod 1 sexually dimorphic in *I. fuscina*); and (7) presence of a basofacial hook on the peduncle of uropod 2 in males.

Ingolfiella quokka differs from *I. australiana* Lowry and Poore, 1989, another Australian ingolfiellid. This species shares characters with species belonging to the subgenus *Trianguliella* Stock, 1976. Both species have (1) a small semicircular eyelobe; (2) antenna 2 flagellum of five articles; (3) accessory flagellum of antenna 1 of three articles, the last one minute; (4) dactylus of gnathopod 1 with four serrations; and (5) pleopods 2 and 3 subtriangular in both sexes. However, *I. australiana* is quite different from *I. quokka*: (1) antenna 1 flagellum of five articles; (2) maxilla 2, inner and outer plates with five plumose setae; (3) gnathopod 2 palm with distal triangular tooth and quadrate tooth separated by a notch; (4) pereopods 5 and 6, dactylus with unguis not defined; (5) pleopod 1 digitiform in male with two apical setae, and subtriangular in female with one seta: (6) uropod 1 has a ventral peduncular row of stout setae (not reported in any other ingolfiellidean); and (7) uropod 2 without basofacial hook on peduncle, and with five obliquely transverse rows of setae (not complex setae).

ACKNOWLEDGEMENTS

We thank Ronald Vonk, Zoological Museum of Amsterdam, The Netherlands for comments on a first draft of this paper.

REFERENCES

Dahl, E. (1977). The amphipod functional model and its bearing upon systematics and phylogeny. *Zoologica Scripta* 6: 221–228.

Dojiri, M. and Sieg, J. (1987). *Ingolfiella fuscina*, new species (Crustacea: Amphipoda) from the Gulf of Mexico and the Atlantic coast of North America, and partial redescription of *I. atlantisi* Mills, 1967.

Proceedings of the Biological Society of Washington **100**: 494–505.

Lowry, J.K. and Poore, G.C.B. (1989). First ingolfiellids from the southwest Pacific (Crustacea: Amphipoda) with a discussion of their systematics. *Proceedings of the Biological Society of Washington* **102**: 933–946.

Ruffo, S. and Taglianti, A.V. (1989). Description of a new cavernicolous *Ingolfiella* species from Sardinia, with remarks on the systematics of the genus (Crustacea, Amphipoda, Ingolfiellidae). *Annali del Museo Civico di Storia Naturale Giacomo Doria, Genova* **87**: 237–261.

Stock, J. (1976). A new member of the crustacean suborder Ingolfiellidea from Bonaire, with a review of the entire suborder. *Studies on the Fauna of Curaçao and other Caribbean Islands* **50**: 56–75.

Stock, J. (1977). The zoogeography of the crustacean suborder Ingolfiellidea with descriptions of new West Indian taxa. *Studies on the Fauna of Curaçao and other Caribbean Islands* **55**: 131–146.

Stock, J. (1979). New data on taxonomy and zoogeography of ingolfiellid Crustacea. *Bijdragen tot de Dierkunde* **45**: 181–190.

Manuscript received January 9 2003; accepted 18 June 2003

S1083

Guide to Authors

Subject Matter:

Reviews, observations and results of research into all branches of natural science and human studies will be considered for publication. However, emphasis is placed on studies pertaining to Western Australia. Longer papers will be considered for publication as a Supplement to the *Records of the Western Australian Museum*. Short communications should not normally exceed three typed pages and this category of paper is intended to accommodate observations, results or new records of *significance*, that otherwise might not get into the literature, or for which there is a particular urgency for publication. All material must be original and not have been published elsewhere.

Presentation:

Authors are advised to follow the layout and style in the most recent issue of the *Records of the Western Australian Museum* including headings, tables, illustrations and references.

The title should be concise, informative and contain key words necessary for retrieval by modern searching techniques. An abridged title (not exceeding 50 letter spaces) should be included for use as a running head.

An abstract must be given in full length papers but not short communications, summarizing the scope of the work and principal findings. It should normally not exceed 2% of the paper and should be suitable for reprinting in reference periodicals.

The International System of units should be used.

Numbers should be spelled out from one to nine in descriptive text; figures used for 10 or more. For associated groups, figures should be used consistently, e.g. 5 to 10, not five to 10.

Spelling should follow the *Concise Oxford Dictionary*.

Systematic papers must conform with the International Codes of Botanical and Zoological Nomenclature and, as far as possible, with their recommendations.

Synonymies should be given in the short form (taxon, author, date, page) and the full reference cited at the end of the paper. All citations, including those associated with scientific names, must be included in the references.

Manuscripts:

The original and two copies of manuscripts and figures should be submitted to the Editors, c/- Publications Department, Western Australian Museum, Francis Street, Perth, Western Australia 6000. They must be in double-spaced typescript on A4 sheets. All margins should be at least 30 mm wide. Tables plus heading and legends to illustrations should be typed on separate pages. The desired position for insertion of tables and illustrations in the text should be indicated in pencil. Tables should be numbered consecutively, have headings which make them understandable without reference to the text, and be referred to in the text.

High quality illustrations are required to size (16.8 cm x 25.2 cm) or no larger than 32 cm x 40 cm with sans serif lettering suitable for reduction to size. Photographs must be good quality black and white prints, not exceeding 16.8 cm x 25.2 cm. Scale must be indicated on illustrations. All maps, line drawings, photographs and graphs, should be numbered in sequence and referred to as Figure/s in the text and captions. Each must have a brief, fully explanatory caption. On acceptance a computer disk containing all corrections should be sent with amended manuscript. The disk should be marked with program (e.g. Word, WordPerfect, etc).

In papers dealing with historical subjects references may be cited as footnotes. In all other papers references must be cited in the text by author and date and all must be listed alphabetically at the end of the paper. The names of journals are to be given in full.

Processing:

Papers and short communications are reviewed by at least two referees and acceptance or rejection is then decided by the editors.

The senior author is sent one set of page proofs which must be returned promptly.

The senior author will receive fifty free offprints of the paper. Additional offprints can be ordered at page proof stage.

Records of the Western Australian Museum
Volume 22 Part 1 2003

CONTENTS

N. Warburton, C. Wood, C. Lloyd, S. Song and P. Withers
The 3-dimensional anatomy of the North-Western Marsupial Mole (*Notoryctes caurinus* Thomas 1920) using computed tomography, X-ray and magnetic resonance imaging 1

F.E.Wells and H. Morrison
Description of *Volutoconus hargreavesi calcarelliformis* subsp. nov. (Mollusca: Volutidae) from northwestern Australia 9

R.L. Hoffman
A new genus and species of trigoniuline milliped from Western Australia (Spirobolida: Pachybolidae: Trigoniulinae) 17

I. Bartsch
Psammophilous halacarids (Halacaridae, Acari) from Dampier, Western Australia. Description of species and faunal comparison of the mesopsammal halacarid fauna of western and eastern Australia 23

I. Maryanto
Taxonomic status of the ricefield rat *Rattus argentiventer* (Robinson and Kloss, 1916) (Rodentia) from Thailand, Malaysia and Indonesia based on morphological variation 47

G.C.B. Poore and W.F. Humphreys
Second species of *Mangkurtu* (Spelaeogriphacea) from north-western Australia 67

S. Gallego Martínez and G.C.B. Poore
A new spècies of ingolfiellid amphipod (Crustacea: Amphipoda) from Western Australia 75

Dates of Publication

Records of the Western Australian Museum

Volume 21, Part 1	1 May 2002
Volume 21, Part 2	18 June 2002
Volume 21, Part 3	20 November 2002
Volume 21, Part 4	27 June 2003